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Internationalisation Dynamics in Contemporary South American Life Sciences. The Case of Zebrafish

Rodrigo Liscovsky Barrera

Doctor of Philosophy
Science and Technology Studies
School of Social and Political Science
The University of Edinburgh
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Abstract

We tend to assume that science is inherently international. Geographical boundaries are not a matter of concern in science, and when they do – e.g. due to the rise of nationalist or populist movements – they are thought to constitute a threat to the essence of the scientific enterprise; namely, the global mobility of ideas, knowledge and researchers. Quite recently, we also started to consider that research could become ‘more international’ under the assumption that in doing so it becomes better, i.e. more collaborative, innovative, dynamic, and of greater quality. Such a positive conceptualisation of internationalisation, however, rests on interpretations coming almost exclusively from the Global North that systematically ignore power dynamics in scientific practice and that regard scientific internationalisation as an unproblematic transformative process and as a desired outcome.

In Science and Technology Studies (STS), social research on model organisms is perhaps the clearest example of the influence of the dominant vision of internationalisation. This body of literature tends to describe model organism science and their research communities as uniform and harmonious international ecosystems governed by a strong collaborative ethos of sharing specimens, knowledge and resources. But beyond these unproblematic descriptions, how does internationalisation actually transform research on life? To what extent do the power dynamics of internationalisation intervene in contemporary practices of knowledge production and diffusion in this field of research?

This thesis revisits the dynamics and practices of scientific internationalisation in contemporary science from the perspective of South American life sciences. It takes the zebrafish (*Danio rerio*), a small tropic freshwater fish, originally from the Ganges region in India and quite popular in pet shops, as a case study of how complex dynamics of internationalisation intervene in science. While zebrafish research has experienced a remarkable growth in recent years at the global scale, in South America its growth has been unprecedented, allowing average laboratories, which often operate with small budgets and with less well-developed science infrastructures, to conduct world-class research.

My approach is based on a consideration of internationalisation as a conceptual model of change. I consider internationalisation to be a process essentially
marked by tensions in the spatial, cognitive and evaluative dimensions of scientific practice. These tensions, I claim, are not just a key feature of internationalisation, but also aspects of a conceptual opposition that is geared towards explaining how change comes about in science. By studying the dynamics of internationalisation, I seek to understand various transformations of zebrafish research: from its construction as a research artefact to its diffusion across geographical boundaries. My focus on South America, on the other hand, helps me to understand the complexity of such dynamics beyond the lenses of the dominant discourse of internationalisation that prevails in the STS literature on model organisms. I use mixed-methods (i.e. semi-structured interviews, document analysis, bibliometrics and social network analysis) to observe and interpret transformations of internationalisation at different scales and levels.

My analysis suggests first, that internationalisation played an important role in the construction of the zebrafish as a model organism and that, in the infrastructures and practices of resource exchange that sustain the scientific value of the organism internationally, dynamics of asymmetry and empowerment problematise the collaborative ethos of this community. Second, I found that collaborative networks – measured through co-authorships – also played an important role in the diffusion of zebrafish as a model organism in South America. However, I did not find a clear indication of international dependency in the diffusion of zebrafish, explained by a geographical concentration of scientific expertise in the zebrafish collaboration network. Rather than exposing peripheral researchers to novel ideas, networks of international collaboration seem to be more related to access to privileged material infrastructures resulting from the social organisation of scientific labour worldwide. Lastly, by examining practices of biological data curation and researchers’ international mobility trajectories, I describe how dynamics of internationalisation shape the notion of research excellence in model organism science. In this case, I found mobility trajectories to play a key role in boosting researchers’ contributions to the community’s database, especially among researchers from peripheral communities like South America. Overall, while these findings show the value of considering internationalisation as a conceptual model of change in science, more research is needed on the intervention of complex dynamics of internationalisation in other cases and fields of research.
Lay summary

When we think of science, we think of it as international by nature. Geographical boundaries are not a matter of concern in science, and when they do – e.g. due to the rise of nationalist or populist movements – they are thought to constitute a threat to the essence of the scientific enterprise; namely, the global exchange of ideas, knowledge and researchers. Quite recently, we also started to consider that research could become ‘more international’ under the assumption that in doing so it becomes better, i.e. more collaborative, innovative, dynamic, and of greater quality. Such a positive conceptualisation of internationalisation, however, rests on interpretations coming almost exclusively from the Global North that systematically ignore power dynamics in scientific practice and that regard scientific internationalisation as an unproblematic transformative process and as a desired outcome.

The life sciences is a field where the influence of this positive vision of internationalisation is clear. Initially, in social studies of science, the life sciences were not regarded as a field with strong internationalisation dynamics such as physics or astronomy, where international collaboration and the global mobility of scientists are considered key features of these fields of research. It has been more recently that the life sciences begun to be considered an increasingly large, collaborative, international and networked field, as illustrated by the massive international collaborative efforts behind the Human Genome Project.

Within the life sciences, social research on model organism science is perhaps the clearest example of the impact of the dominant vision of internationalisation. Model organisms – Drosophila and as C. Elegans are well-known examples – are non-human species that are studied comprehensively to understand different biological phenomena, with the intention that the knowledge generated on the model will be applicable to other more complex organisms, such as humans. Social researchers studying model organism science tend to describe these research communities as highly collaborative, sustained by large networks and far-reaching communal infrastructures that ensure specimens, knowledge and resources are exchanged across borders in a freely and unselfish manner. However, the lack of discussions on the power dynamics present in these international communities shows the extent in which in the social study of the life sciences, scholars have continued to take for granted the notion of internationalisation.
In this thesis, I take a relatively novel model organism, the zebrafish (*Danio rerio*) – a small tropic fresh water fish, originally from the Ganges region in India – to study how the power dynamics of internationalisation intervene in science. I focus on the perspective of South America, where zebrafish research has experienced an outstanding growth to the point it has outpaced research conducted on other model organisms. This success is said to be facilitated by the technical features of the model (i.e. cost-space efficiency, short breeding and life cycles, etc.) and more importantly by the support of a strong and highly collaborative international community. Therefore, through this case, I aim to investigate the extent to which power dynamics are also present in what at first sight look like harmonious global research ecosystems in the life sciences.

I consider internationalisation to be a process essentially marked by tensions in the spatial, cognitive and evaluative dimensions of scientific practice. These tensions, I claim, are not just a key feature of internationalisation, but also aspects of a conceptual opposition that is geared towards explaining how change comes about in science. For instance, the diffusion of scientific knowledge takes place in a context marked by higher levels of transnational collaboration and mobility, but also by a greater spatial concentration of scientific production, namely in countries of the Global North. Internationalisation dynamics, therefore, do not just refer to the international dimension of science, but also to its counter forces. To study these complex dynamics, I make use of mixed-methods (i.e. semi-structured interviews, document analysis, bibliometrics and social network analysis) that allow me to observe and interpret transformations of internationalisation at different scales and levels.

My research focuses on specific transformations taking place in zebrafish science. I first study the construction of zebrafish as a research tool and the formation of the early zebrafish community. Using documents (i.e. scientific papers and personal accounts by zebrafish pioneers), I reconstruct the history of the standardisation process of zebrafish and I explain how various internationalisation dynamics played a key role in its construction as a genetic tool. I also examine practices of resource exchange and acquisition in the zebrafish community. One the one hand, I review existing guidelines and protocols for exchanging fish specimens through the Zebrafish International Resource Center (ZIRC) – the centralised facility that maintains wild type and mutant stocks of zebrafish and makes them available to researchers across the world – to understand how practices of resource exchange
are conceived and regulated in the global zebrafish community. On the other hand, based on the analysis of interviews with South American zebrafish researchers, I describe practices of resource exchange taking place in peripheral settings and outside formal channels of exchange. My analysis confirms the existence of dynamics of asymmetry and empowerment in these practices that contribute to problematise the research ethos of zebrafish science and disrupt the notion of the zebrafish community as a uniform, borderless, and harmonious ecosystem.

I then study the role played by distinct collaborative networks in the diffusion of zebrafish as a model organism in South America and in other scientific regions from the mid-1990s onwards, when zebrafish consolidated as powerful genetic tool. I collected a large sample of scientific papers indexed in Scopus, a major bibliometric database, where zebrafish was used as a model organism. From this literature, and using techniques from Social Network Analysis (SNA), I constructed the network of collaboration of zebrafish research. In my analysis, I first describe the spatial structure of this large collaborative network expanding over a period of more than twenty years (1996-2016). Following this, I use Machine Learning techniques to model the influence of different geographical networks in the diffusion of zebrafish as a model organism. My goal was to study the extent to which access to networks of experienced users of the model, presumably located outside the local milieu, is factor that explains the diffusion of the zebrafish in a peripheral regional community such as South America. Results indicate that collaborating with institutions who have a previous experience in the use of the zebrafish model is a key explanatory factor of the diffusion of this model organism in South America, though probabilities of adoption in this model are considerable modest. Moreover, I could not find a clear indication of international dependency in this process, explained by a geographical concentration of scientific expertise in the zebrafish collaboration network. In light of this, and based on a subsequent analysis of interviews, I set out to investigate the meaning that international collaboration has for South American zebrafish researchers. Through this qualitative analysis, I was able to confirm that networks of international collaboration are more related to access to privileged material infrastructures resulting from the social organisation of scientific labour worldwide, rather than being exposed to novel ideas.

Lastly, I look at the relationship between internationalisation and the notion of ‘excellence’ in zebrafish research using a combination of qualitative and bibliometric
techniques. First, I study practices of biological data curation taking place at the Zebrafish Information Network (ZFIN), the zebrafish international online database, which contains curated information of zebrafish research worldwide. I found that biocuration practices in ZFIN reproduce the existing uneven structure of knowledge diffusion and circulation in science, based on publications in mainstream journals. Because of this, South American zebrafish researchers’ visibility within the ZFIN echoes their previous visibility within the global publication-based system. Second, I collected more than 2 million publications and I use affiliation data to reconstruct the mobility trajectories of zebrafish researchers, from Latin America and other world regions. I then examine how international mobility interacts with researchers’ contributions and visibility within the zebrafish database in the form of curated annotations (i.e. registered genes, genotypes and fish lines). In this case, I found mobility trajectories to play a key role in boosting researchers’ contributions to the communal database, especially among researchers from peripheral communities like South America.

The analyses conducted in this thesis deliver insights from various points of view – i.e. theoretical, methodological and policy-making – that contribute to expand our understanding of scientific internationalisation. Taken together, these findings show the value of considering internationalisation as a conceptual model of change in science, although more research is needed on the intervention of complex dynamics of internationalisation in other cases and fields of research.
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Declaration

I declare that this thesis was composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or processional qualification. Parts of this work have been published in:

- Limited material from Chapter 3 has been previously published in two book review papers. One published in Medical History, ‘Patrick Manning and Mat Savelli (eds), Global Transformations in the Life Sciences, 1945–80’ (Liscovsky Barrera 2019b) and the other published in Social & Cultural Geography, ‘Agnieszka Olechnicka, Adam Ploszaj, and Dorota Celińska-Janowicz, The geography of scientific collaboration’ (Liscovsky Barrera 2019c).

- Parts of the content of Chapter 4 dealing with the combination of methods in STS have been previously published in the proceeding of the 23rd International Conference on Science and Technology Indicators (Leiden, The Netherlands), in a paper titled ‘Overcoming the divide in SSTI: a mixed method and multi-level analysis of internationalisation in South American biomedical research’ (Liscovsky Barrera 2018).

- In Chapter 4, the material related to the social network approach in bibliometrics was prepared by myself and presented to students attending the Economic and Social Research Council’s ‘Bibliometrics and Social Network Analysis’ workshop, which I co-organised together with another PhD Student. I was solely responsible for the teaching of the introduction to Social Network Analysis (SNA) and co-authorship network analysis.

- Parts of the content of Chapter 6 were published in a paper presented at the 17th International Conference on Scientometrics & Informetrics (Rome, Italy), titled ‘The Diffusion of Zebrafish in Latin American Biomedical Research. A Study Based on Bibliometric Dynamic Network Data’ (Liscovsky Barrera 2019a).

- Parts of the content of Chapter 6 was adapted by myself for publication in a chapter of an upcoming book in Spanish, published by CIS (Madrid, Spain), Redes en Latinoamérica, titled ‘La Difusión del Pez Cebra en la Investigación Biomédica’ (Liscovsky Barrera 2021).

Rodrigo Liscovsky Barrera
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List of abbreviations

ANT – Actor Network Theory
ASOC – Asia and Oceania
ATCC – American Type Culture Collections
BIOLAC – Biotechnology Programme for Latin America and the Caribbean
CERN – European Organization for Nuclear Research
CGC – Caenorhabditis Genetics Center
EU – European Union
COST – European Cooperation in Science and Technology program
CSH – Cold Spring Harbor
CSHL – Cold Spring Harbor Laboratory
CWTS – Centre for Science and Technology Studies
CZPM – Chinese Zebrafish Principle Investigator Meeting
CZRC – China Zebrafish Resource Centre
DIT – Diffusion of Innovations Theory
EAIE – European Association for International Education
EC – European Commission
ECLAC – Economic Commission for Latin America and the Caribbean
EHA – Event History Analysis
SciELO – Scientific Electronic Library Online
EMBL – European Molecular Biology Laboratory
EMBO – European Molecular Biology Organization
ERA – European Research Area
ERC – European Research Council
ESF – European Science Foundation
ESRC – Economic and Social Research Council
EU – European Union
EZPM – European Zebrafish Principal Investigator Meetings
EZRC – European Zebrafish Resource Centre
FP – Framework Programmes
GATS – General Agreement in Trade and Services
GO – Gene Ontology
HEP – High-Energy Physics
HES – Higher Education Studies
HGP – Human Genome Project
ICGEB – International Centre for Genetic Engineering and Biotechnology
ICM – Chile’s Millennium Science Initiative
IIE – Institute of International Education
IMB – Institute of Molecular Biology
INPA – Amazônia National Research Institute
IZFS – International Zebrafish Society
LASTSTD – Latin American School of Thought in Science, Technology and Development
LAZEN – Latin American Zebrafish Network
LTERN – Long-Term Ecological Research Network
MCSA – Multichannel Sequence Analysis
MeSH – Medical Subject Headings
MGH – Massachusetts General Hospital
MIT – Massachusetts Institute of Technology
MODs – Model Organism Databases
MPIDB – Max Planck Institute for Developmental Biology
NAFSA – Association of International Educators
NAFTA – North American Free Trade Agreement
NASC – Nottingham Arabidopsis Stock Centre
NC – Nomenclature Committee
NEON – National Ecological Observatory Network
NIH – National Institutes of Health
NLM – United States National Library of Medicine
NSF – National Science Foundation
NZRC – National Zebrafish Research Conference of China
OAS – Organisation of American States
OECD – Organisation for Economic Co-operation and Development
ORD – Open Research Data
PA – Programme Announcement
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tr>
<td>PI</td>
<td>Principal Investigator</td>
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<tr>
<td>PM</td>
<td>Policy Maker</td>
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<td>R&amp;D</td>
<td>Research and Development</td>
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<td>RFA</td>
<td>Request for Applications</td>
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<td>RICYT</td>
<td>Ibero-American Network of Science and Technology Indicators</td>
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<td>RM</td>
<td>Research Manager</td>
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<td>S&amp;T</td>
<td>Science and Technology</td>
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<td>SA</td>
<td>Sequence Analysis</td>
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<td>SCI</td>
<td>Science Citation Index</td>
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<td>SGSSS</td>
<td>Scottish Graduate School of Social Science</td>
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<td>SNA</td>
<td>Social Network Analysis</td>
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<td>SQL</td>
<td>Structured Query Language</td>
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<td>SSK</td>
<td>Sociology of Scientific Knowledge</td>
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<td>STI</td>
<td>Science, Technology and Innovation</td>
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<td>STIS</td>
<td>Science, Technology and Innovation Studies</td>
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<td>STS</td>
<td>Science and Technology Studies</td>
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<td>TOA</td>
<td>Time of Adoption</td>
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<td>TZCC</td>
<td>Trans-NIH Zebrafish Coordinating Committee</td>
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<td>UNESCO</td>
<td>United Nations Educational, Scientific and Cultural Organization</td>
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<td>UV</td>
<td>Ultraviolet</td>
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<td>WTO</td>
<td>Trade World Organization</td>
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<td>WWII</td>
<td>World War 2</td>
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<td>XML</td>
<td>Extensible Markup Language</td>
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<td>ZFA</td>
<td>Zebrafish Anatomy</td>
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<td>ZFIN</td>
<td>Zebrafish Information Network</td>
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<td>ZFN</td>
<td>Zinc Finger Nucleases</td>
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<td>ZFS</td>
<td>Zebrafish Stage</td>
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<td>ZIRC</td>
<td>Zebrafish International Resource Center</td>
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<td>ZMP</td>
<td>Zebrafish Mutation Project</td>
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Supplementary Materials

All the datasets, code scripts and visuals used in the quantitative analysis of this thesis are included in the Supplementary Materials file. Below I describe the content of each folder briefly.

Chapter 4:

Data folder:

- *Zebrafish pubs per collaboration type (1995-2016).csv*. A list file containing the count of publications of zebrafish research for the period 1995-2016 classified according to the collaborative nature of the papers.
- *ZFIN_statistics_community.csv*. A list file containing descriptive statistics of the zebrafish community.

Visuals:

- *Zebrafish_pubs_collab_type_1996-2016.png*. Figure depicting the evolution of zebrafish publications for the period 1995-2016 classified according to the collaborative nature of the papers.
- *ZFIN_community.png*. Figure depicting the evolution of the zebrafish community from for the period 1998-2016

Chapter 5:

Data folder:

- *Development_Issue_1996.gexfi*. A Gephi working environment containing the edgelist and nodelist of Development’s 1996 special Issue (i.e. the ‘Big Screens’). Each node is an author, and the edge is a co-authorship event.
- *Development_Issue_1996_nodelist.xlsx*. An Excel file with details of each node (author) of the Big Screens network.
- *Streisinger_publication_record.csv*. A list file containing counts of George Streisinger’s publications.

Visuals:

- *Development_Issue_1996_Pub_Affil.png*. Figure depicting the 1996 Big Screens co-authorship network. Node colours according to the authors’ affiliation at the time of conducting the screenings.
- *Development_Issue_1996_Actual_Affil.png*. Figure depicting the 1996 Big Screens co-authorship network. Node colours according to the authors’ affiliation at the time of the publication of the special issue.
- *Streisinger_publication_record.png*. Figure depicting the evolution of Streisinger’s publication record.
Chapter 6:
The majority of the quantitative analyses conducted in Chapter 6 were done using the R programming language. Therefore, and in order to facilitate the replication of results, I created an R project environment. The R project is called “Chapter 6_Analysis.Rproj”. By using this R project environment, users are not required to set up their own working directory. Users can open this file directly in R studio, navigate through the different datasets and use the scripts to run all the analysis conducted in this chapter.

The environment contains a customised internal directory that has the following structure:

- **Code folder**: contains the R script to run the analyses. Users can make use of the script outline to navigate to specific sections of the script. The code automatically installs the required libraries if they are not already installed.
- **Data folder**: contains all the original datasets in the chapter. The folder contains subfolders with copies files created through the scripts.
- **Visuals folder**: contains the output visuals of the chapter.

The resources provided for this chapter are the following:

Original datasets:

- **Attribute_INST(1996-2017).csv**: An attribute list file containing details of each institution, including the year of publication, the number of published articles, time of adoption (TOA), size of their collaboration network, etc.
- **Dif_Net_Attrs.csv**: An attribute list file containing dynamics attributes of the diffnet object.
- **attrs_static_with_mobility&ref.csv**: An attribute list file containing static and dynamics attributes of the diffnet object.
- **whole(lagged)_exp_per_GLOBAL.csv**: A matrix file containing lagged network exposure files for the entire diffnet object. This matrix was used to extract the base matrices of each regional community, found in the folder ‘Bases’.
- **1996-2000.net**: A net file that can be opened using the software Gephi to visualise the institutional co-authorship network for the period 1996-2000.
- **2001-2005.net**: A net file that can be opened using the software Gephi to visualise the institutional co-authorship network for the period 2001-2005.
- **2006-2010.net**: A net file that can be opened using the software Gephi to visualise the institutional co-authorship network for the period 2006-2010.
- **20011-2016.net**: A net file that can be opened using the software Gephi to visualise the institutional co-authorship network for the period 2011-2016.
- **1996-2000.csv**: An edge list file containing all the co-authorships of zebrafish research papers between institutions for the period 1996-2000.
• **2001-2005.csv.** An edge list file containing all the co-authorships of zebrafish research papers between institutions for the period 2001-2005.
• **2006-2010.csv.** An edge list file containing all the co-authorships of zebrafish research papers between institutions for the period 2006-2010.
• **20011-2016.csv.** An edge list file containing all the co-authorships of zebrafish research papers between institutions for the period 20011-2016.

**Scripts:**

• *Script_Chapter_6_Zebrafish_Network_Centralities.R.* An R script to analyse the network centrality scores of all of the research institutes of the global zebrafish network (1996-2016).
• *Script_Chapter_6_Network_Diffusion.R.* An R script to build the zebrafish diffusion model based on bibliometric network data. The script contains all the necessary steps to compute network exposure scores and run the classification tree analysis.

**Visuals:**

• *Weighted_degree_scores.png.* Figure depicting the distribution of weighted degree scores of research institutes in the four giant components (1996-2016).
• *Normalized_betweenness_scores.png.* Figure depicting the distribution of betweenness centrality scores of research institutes in the four giant components (1996-2016).

**Chapter 7:**

**Data:**

• *Total pub counts in each db.csv.* A file list containing counts of publications in each major bibliographic database (WoS, Scopus, PubMed) and ZFIN.
• *Pub overlaps between db.csv.* A file list containing counts of publication overlaps between selected databases (WoS, Scopus, PubMed-ZFIN).
• *Language pub WOS_SCOPUS_ZFIN.csv.* A file list containing counts of publications classified according to the language of the paper in selected databases (WoS, Scopus, PubMed-ZFIN).
• *directional_travellers_flows_edgelistl.csv.* An edge list file containing mobility flows of zebrafish researchers classified as directional travellers (1996-2016).
• *migrant_flows_edgelist.csv.* An edge list file containing mobility flows of zebrafish researchers classified as migrants (1996-2016).
• *mobility_flows.gephi.* A Gephi working environment containing mobility flows of zebrafish researchers (1996-2016).
• *Mobility_ZFIN.pbix.* An interactive Power BI data model containing data tables and visuals of the interaction between international mobility and curated annotations in the ZFIN database.

**Visuals:**

• *directional_travellers_flows.png.* Figure depicting the network of mobility flows of zebrafish researchers classified as directional travellers (1996-2016).
• *migrants_flows.png.* Figure depicting the network of mobility flows of zebrafish researchers classified as migrants (1996-2016).
Chapter 1: Introduction

We tend to assume that science is inherently international. Geographical boundaries are not a matter of concern in science, and when they do – e.g. due to the rise of nationalist or populist movements – they are thought to constitute a threat to the essence of the scientific enterprise; namely, the global mobility of ideas, knowledge and researchers. Quite recently, we also started to consider that science could become ‘more international’ under the assumption that in doing so it becomes better, i.e. more collaborative, innovative, dynamic, and of greater quality. This transformative capacity, the idea that the international character of science could be increased – and therefore managed –, forms the basis of the concept of internationalisation, which developed in Higher Education Studies (HES) in the 1990s. Nowadays, internationalisation has evolved to become a buzzword and a container concept that includes everything that relates to the international (de Haan 2014).

Taken together, definitions of internationalisation in fact make up a collection of imaginaries coming almost exclusively from the Global North and mostly being concerned with addressing and adapting to the challenges raised by globalisation. Internationalisation, in other words, has been largely defined from and for U.S and European contexts, and is commonly understood as a process bringing mainly positive transformations in education and research. From this perspective, public policies towards internationalisation seek to strengthen research excellence and innovation performance, enlarging the attractiveness of research and education systems in order to better the capability to compete in the global market, as well as responding to global problems more efficiently by sharing common ideas and values (see Georghiou 1998; Van den Besselaar et al. 2012). Moreover – and for a number of years now –, internationalisation not only has become a policy goal in itself but it is also seen as an instrument to support other goals (Boekholt et al. 2009). In Europe, for instance, the concept of scientific internationalisation is a fundamental pillar of the European Research Area (ERA) and is conceived as a two-tier ‘system’ designed to balance cooperation and competition at the scale of Europe and the world simultaneously (ESF 2010).

While definitions of internationalisation vary according to different policy rationales and objectives (de Wit 2001; Brandenburg and de Wit 2015), a common
feature among them is the conceptualisation of internationalisation as an unproblematic process and as a desired outcome; i.e. as something that should be pursued, promoted and defended, if necessary. In recent years, however, some scholars in HES have started to reflect critically on the changing definitions of internationalisation and also by coming out in favour of expanding the discourse beyond Western and neo-colonial constructs and by welcoming views from developing countries (see Knight 2011; but especially Jones and de Wit 2012; de Wit 2013). These developments in the discourse of internationalisation of HES, although still far from becoming the dominant view, show that internationalisation is in fact a more complex and multi-faceted phenomenon than initially thought, and one that deserves further scrutiny.

**Internationalisation dynamics of science**

Unlike HES, in Science and Technology Studies (STS), thus far there has not been a collective debate about the meaning of internationalisation (Woldegiyorgis, Proctor, and de Wit 2018). Internationalisation is still a phenomenon largely understood through the lens of the Global North; namely as a process free from conflict that leads to better science. This is observed in evaluation and scientometric studies describing how research impact and visibility are greatly related to practices of international mobility and collaboration (see Sugimoto et al. 2017; Robinson-Garcia et al. 2019; Halevi, Moed, and Bar-Ilan 2016; Edler 2007; Edler, Fier, and Grimpe 2011; Glänzel, Schubert, and Czerwon 1999; Narin, Stevens, and Whitlow 1991; Zhou and Leydesdorff 2006; Persson, Glänzel, and Danell 2004). In social studies of science, the influence of the dominant view of internationalisation can be appreciated in studies of the so-called ‘Big Sciences’, namely high-energy physics (Price 1963; Galison 1997; Knorr-Cetina 1999; Shrum, Genuth, and Chompalov 2007). Along with an increase in numbers (e.g. researchers, publications, investments, institutions, disciplines and instruments), Big Science has evolved to entail a process of *greater internationalisation* involving a geographical expansion and growing multinational cooperation that adds another layer of analysis to understand how science gets ‘big’ (Vermeulen 2009).

The life sciences are an interesting case of the intervention of the internationalisation discourse in STS. Compared to big physics, the life sciences were not regarded initially as Big Science, but rather as a bodily and lab-bench science governed by an individual ontology (Knorr-Cetina 1999). It has been more recently
that research on life has begun to be considered as another form of Big Science. That is, a research field that has become increasingly large, collaborative, international and networked (Vermeulen 2009; Vermeulen, Parker, and Penders 2013).

Within this body of research, social studies on model organism research – *Drosophila* and as *C. Elegans* are well-known examples – are perhaps the clearest cases of the impact of the dominant vision of internationalisation in STS. Scholars in this field have largely described research on model organisms and their scientific communities as driven by a strong collaborative ethos and networks of exchange of specimens, knowledge and resources (R. E. E. Kohler 1994; Ankeny and Leonelli 2011; Rosenthal and Ashburner 2002; N. C. Nelson 2013). Moreover, the community infrastructures designed to support these exchanges are taken as key examples of the organisational transformations induced by internationalisation dynamics in this field of research. Particularly, stock centres and online databases are said to have displaced traditional communication means, dramatically increasing the quantity of information available, and creating new standards and guidelines for what counts as reliable scientific knowledge (Leonelli and Ankeny 2012; 2015). The lack of discussions on the power dynamics present in these international communities, however, shows the extent in which in the social study of the life sciences, scholars have continued to take for granted the notion of internationalisation.

**The Latin American take on internationalisation**

While critical perspectives on related concepts such as universalism, transnational, multinational and globalisation exist in the STS literature (Leclerc and Gagné 1994; Hakala 1998; Somsen 2008; 2014), it is in Latin American STS where researchers can find a long and rich record of research on internationalisation with a strong critical component. Nearly thirty years before the concept was developed in HES, the first STS thinkers in this region stood up to denounce inequalities present in the international scientific system (see Sábato and Botana 1968; Varsavsky 1969; Herrera 1972). This group of pioneers linked the underdevelopment of Latin American countries to dynamics of dependency and asymmetry in international science and technology.

Later on, once STS started to consolidate in Latin America from the 1990s onwards, Latin American researchers continued developing critical approaches towards internationalisation through in-depth sociological and anthropological
research, in which the life sciences featured prominently. Contemporary Latin American scholars have approached the life sciences from a socio-historical perspective and have shown how internationalisation played a key – and most of the times also a conflicting – role in the development of some disciplines and fields of research in the region (Cueto 1989; Velho 1996; Kreimer and Lugones 2002). This more recent body of research is largely built around the concept of ‘peripheral science’ (Díaz, Texera, and Vessuri 1983) that aims to describe, through historical or contextualised cases, how scientific knowledge is produced autonomously in spite of inadequate conditions.

Notwithstanding the importance of these studies for understanding internationalisation, there is still a need to further understand how internationalisation dynamics intervene in contemporary Latin American science, and specially, in fields of research on life, such as model organism science, where the dominant take on internationalisation prevails.

**From a Manual to a Fish**

As is often the case with research spreading over a number of years, the final picture of this thesis resembles little to the original proposal. Five years ago when I submitted a research proposal along with my application, my goal was to test indicators for evaluating dynamics of scientific internationalisation in Latin America. While as a technician working with statistics of science, technology and innovation in Argentina, I came across a methodological manual for measuring and evaluating the internationalisation of science and technology exclusively devoted to Latin American countries. The Ibero-American Network of Science and Technology Indicators (RICYT) – a regional policy organisation that brings together all the science and technology agencies of the region plus Spain and Portugal – published in 2007 the ‘Manual of Science and Technology Internationalisation Indicators – the Santiago Manual’ (RICYT 2007). Adapted to the heterogeneous character of the region, the indicators included in this manual were said to constitute a response to the interests aroused among Latin American policy makers on internationalisation dynamics (Ibid p.7). However, almost 10 years after its publication, I found no indications that the guidelines and recommendations provided by the Manual had been put into practice.

This lack of implementation, in spite of the stated and widespread interest on internationalisation, caught my attention. Initially, I was keen to apply the indicators of
the Santiago Manual against an empirical setting. My idea was to conduct a comparative analysis between a few countries and test the suitability of these indicators for capturing dynamics of the internationalisation in a research field where internationalisation has been historically present in Latin America: the life sciences. My focus was going to be the Manual, the people involved in its production and the opportunities and limitations of using standardised indicators to capture dynamics of scientific internationalisation in a diverse and contrasting region such as Latin America.

From the beginning, however, the project had already evolved considerably. During my first year at the Masters (I followed the 1+3 track), I was introduced to a body of STS literature that was unknown to me; i.e. studies on scientific collaboration and the organisation of science; philosophy of statistics and sociology of indicators; studies on knowledge diffusion and the travels of ideas, social studies of the life sciences, etc. In addition, during the first year of the project, together with other PhD students coming from different countries of Latin America, we started a weekly reading group in Latin American STS with the aim of complementing the training we received at Edinburgh with past and contemporary STS research conducted in our home countries. This eventually materialised in a workshop were we brought together a small group of researchers from both sides of the Atlantic to reflect on various themes affecting future research in this field. All of this made me reflect more on the concept of internationalisation from a sociological perspective and about its complexities in Latin America.

Together with my supervisors, we agreed that conducting fieldwork would help me explore further on these issues. From March to August 2018, I travelled to Argentina, Chile and Uruguay and conducted semi-structured interviews with scientists working in various areas of the life sciences as well as with policy-makers and research managers. These meetings allowed me to obtain a first-hand appreciation of what internationalisation looks like beyond abstract concepts or quantitative indicators.

In this trip, I also discovered a growing and fascinating area of research in the life sciences, which uses a freshwater little fish, native of the Ganges region of India, as a model organism to study various biological and biomedical phenomena: the zebrafish. To my surprise, I found that the growth of this model in South America had been unprecedented and led to the formation of interesting collaborative networks.
expanding across borders. The more I learned about the zebrafish – through conversations I had with South American zebrafish scientists as well as from papers and other documents I collected during my visit – the more I realised I could use it as a case study to understand how internationalisation intervenes in contemporary science. I should also admit that, like many of the modellers I interviewed, I ‘got hooked’ to the zebrafish. The researchers’ enthusiasm on this little fish spread to me too.

One thing was clear to me from the beginning though. I wanted to do mixed-method research. I was convinced early on that using both quantitative and qualitative methods would allow me to navigate through the different levels (i.e. micro and macro) at which internationalisation operates (Gornitzka, Gulbrandsen, and Trondal 2003; Zitt and Bassecoulard 2004, 11). In my first year at Edinburgh, I also completed a course on Social Network Analysis (SNA), which became so appealing to me that I eventually ended up tutoring in it. Because SNA can cross multiple levels of explanation simultaneously (i.e. individual, organisation and global structures), I realised it was a powerful methodological approach to integrate in my thesis to study scientific internationalisation from a relational perspective.

Another conclusion of that first year was that even though I had a background in science and technology indicators, I had little knowledge of scientometric and bibliometric techniques applied to social research. Therefore, right after completing my overseas fieldwork, I decided to undertake a 10-week overseas institutional visit to the Centre for Science and Technology Studies (CWTS) at Leiden University in The Netherlands; an international leading interdisciplinary research institute in the field of scientometrics and bibliometrics. This visit not only allowed me to work closely with my external supervisor, but also generated a clear benefit to my PhD experience by providing me with a cutting-edge training in bibliometrics that was not available in Edinburgh. The goal of pursuing a mixed-method research also gave me the opportunity to contribute to efforts to build collaboration networks between my department, Science, Technology and Innovation Studies unit (STIS) and CWTS, and ultimately between qualitative and quantitative STS. In this case, together with another STIS PhD student and in collaboration with CWTS, I organised a training workshop in Edinburgh on scientometrics, bibliometrics and SNA open to postgraduate students from Scottish universities.
This journey took me to develop the present thesis. Surely, one cannot cover all the aspects one wishes to inquire about a research topic as vast as scientific internationalisation. As such, I leave for future research the possibility to continue exploring the reasons why methodological manuals such as the Santiago Manual face difficulties of implementation and how they enclose knowledge diffusion mechanisms in themselves. Overall, either through the means of a manual or a fish, internationalisation is a topic that continues to capture my attention.

**Overview of the research**

My goal in this thesis is to revisit dynamics and practices of scientific internationalisation in contemporary South American life sciences. To do so, I will focus on a relatively novel model organism: the zebrafish (*Danio rerio*). The zebrafish is a small (one and a half inches long) tropical fresh-water fish, originally from the Ganges region in India and quite popular in pet shops. In science, the zebrafish is used to study a wide range of biological and biomedical questions and as such, it not only has experienced a remarkable growth at the global scale, but in South America in particular, its growth has been unprecedented (Buske 2012; Gheno et al. 2016; Trigueiro et al. 2020).

The zebrafish (*pez cebra* in Spanish; *peixe-zebra* in Portuguese) constitutes an interesting case to study the complex transformative dynamics of scientific internationalisation in South American life sciences. Its relative economy *vis à vis* other model organisms, its small physical and genomic sizes as well as its short breeding and life cycles has turned the zebrafish into a powerful genetic tool and has increased the prospects of South American laboratories to conducting high-quality research more autonomously. This has translated into a notable growth of publications on zebrafish in this region, which have outpaced the growth rate of publication on other model organisms.

At the same time, the international zebrafish community is often described as a horizontal and highly collaborative community with far-reaching infrastructures giving the impression of a global ecosystem where knowledge and resources are mobilised and exchanged without constraints. By taking the zebrafish as a case study, I therefore aim to investigate the extent to which power dynamics are also present in what at first sight look like harmonious global research ecosystems in the life
sciences. To study this, I make use of mixed-methods techniques that allow me observing and interpreting transformations taking place at different scales and levels.

My approach is based on a consideration of internationalisation as a conceptual model of change. Following a similar approach developed by Vermeulen (2009) on the concept of Big Science, I argue that the concept of ‘scientific internationalisation’ should be considered as a model of transformation in science to the same level as existing conceptual models in STS (e.g. Mode 2 or the Triple Helix). I consider internationalisation to be a process essentially marked by tensions in various dimensions of scientific practice of which three stand out. The first tension is the opposition between the cooperative and competitive ethos of scientific research, also understood as the contrast between the notions of internationalisation and globalisation. The former is often considered closer to the well-established tradition of international cooperation and mobility, of sharing costs, workloads and resources, whereas the latter refers more to competition for resources, prestige and recognition (van Vught, van der Wende, and Westerheijden 2002). Second are spatial tensions, which refer to the conflicting relationship between the national and international contexts in which scientific practice takes place. This expresses for instance in the rapid diffusion of ideas and the growth of mobility and collaboration across borders in contemporary research that is countered with a growing spatial concentration of scientific production and resources (Schott 1991; Gibbons 1994; Leydesdorff and Wagner 2008; Olechnicka, Ploszaj, and Celińska-Janowicz 2018). The third tension exists in the domain of research evaluation. Here, ideas of internationalisation as a highly positive phenomenon that boosts quality and excellence meets resistance by more critical perspectives that regard internationalisation as an asymmetrical phenomenon, which puts pressure on peripheral scientists to publish in mainstream English-language journals or to justify the local relevance of their research (Kreimer 2006; 2015; Vessuri 1994b; 1994a; Vessuri, Guédon, and Cetto 2013).

These tensions, I claim, are not just a key feature of internationalisation but also aspects of a conceptual opposition and power dynamics, which are geared towards explaining how change comes about in science. However, despite its relevance, thus far internationalisation dynamics have not been considered seriously as a research subject of transformations in the life sciences. In light of this, and following the aforementioned approach, I seek to answer the following research
question: *how do dynamics of scientific internationalisation intervene in contemporary practices of knowledge production and diffusion in South American life sciences?*

How are tensions of internationalisation relevant for studying transformations in South American life sciences? Besides being important puzzles for understanding contemporary scientific practice (Gornitzka, Gulbrandsen, and Trondal 2003, 133), addressing these tensions is an adequate approach to study the complex dynamics of internationalisation (see Hackett 2005 who examines the tensions and paradoxes in research collaboration). Moreover, I found these tensions to be present, to a greater or lesser degree, in three key theoretical discussions in STS: (1) the formation of scientific communities, (2) knowledge diffusion processes, and (3) the pursuit of excellence in scientific research. What these themes have in common with each other and with the concept of scientific internationalisation itself, I argue, is a concern with explaining how change comes about in science. Therefore, by conceiving internationalisation as a model of change, I aim to produce new perspectives and insights into key theoretical discussions in STS involving dynamics of knowledge production, diffusion and evaluation in science. Next, I explain briefly what this entails.

First, by considering internationalisation as a conceptual model of change, I seek to generate new understandings as to how scientific communities in the life sciences emerge and construct their research ethos as well as the power dynamics present in them. I found that asymmetries and power configurations derived from the international organisation of research labour are a key factor explaining the formation of scientific communities but hardly considered as such in the relevant literature on the topic (Price 1963; Basalla 1967; Crane 1972; Schott 1991; Knorr-Cetina 1999; Wagner and Fukuyama 2008) and even less so on studies about model organisms communities (R. E. E. Kohler 1994; Leonelli 2007; Ankeny and Leonelli 2011; Leonelli and Ankeny 2012; 2013). Hence, taking the zebrafish as a case study, I will inquire about the role of internationalisation dynamics in the construction of this model organism and the formation of its scientific community at the global scale. Moreover, from the perspective of South American zebrafish science, I will examine dynamics of dependency and empowerment present in practices of resource exchange as well as in the international infrastructures that sustain its proclaimed research ethos.

Second, by considering internationalisation as a model of change, I will address a gap in diffusion studies regarding the relative importance of location (see Anderson and Adams 2008). While the literature on knowledge diffusion has
increasingly stressed the important role played by collaboration networks in knowledge diffusion processes (Valente 2005; Wagner and Leydesdorff 2005; Newman 2001a; Gao and Guan 2012a), there is a continued disagreement over the relative importance of local and global networks as drivers of diffusion in science (Storper and Venables 2004; Bathelt, Malmberg, and Maskell 2004; De Noni, Ganzaroli, and Orsi 2017; Torre and Rallet 2005; Olechnicka, Ploszaj, and Celińska-Janowicz 2018, 130). Here too, internationalisation dynamics in zebrafish research form an ideal case for addressing this challenge. The publications of the results of the first random mutagenesis screens in 1996 – a success that involved laboratories in the U.S and Germany – not only confirmed the strong potential of zebrafish as a research model but also set the ground for its further diffusion across the world where collaborative networks were destined to be highly instrumental. Based on this, I will examine the spatial structure of the zebrafish international collaborative network and I will try to understand the extent to which networks of international, regional and national collaborators had an influence in the diffusion of zebrafish as a model organism in Latin America.

Lastly, through this novel approach on internationalisation I aim to add to discussions on scientific excellence. In scientific research, excellence is a notion that is both dependent on existing evaluation practices and shaped by the collective believes and goals of research communities themselves (Tijssen 2003). Though there is an abundant amount of literature on this topic (see for instance Mahroum 1998; 1999; Ackers 2005; 2008; Basri et al. 2008), we still have little understanding of the mechanisms by which internationalisation affects the notion of excellence in specific research communities such as model organisms. I argue that dynamics of scientific internationalisation in model organism research expanding across various dimensions (i.e. scientific practices of mobility, knowledge infrastructures and evaluation systems) intervene in shaping the notion of excellence. Therefore, by focusing on the zebrafish, my aim is to investigate how the notion of research excellence is constructed in the international zebrafish community and how it interacts with practices of internationalisation; namely with the international mobility trajectories of Latin American zebrafish researchers.

In sum, by studying dynamics of internationalisation of zebrafish research I aim to understand various transformations of zebrafish research: from its construction as a research artefact to its diffusion across geographical boundaries. My focus on
South America, on the other hand, will help me to understand the complexity of such dynamics beyond the lens of the dominant discourse of internationalisation that prevails in the STS literature on model organisms.

**The structure of this thesis**

Following this introduction, in Chapter 2, I provide an overview of the phenomenon of internationalisation. I first discuss the evolution of the concept of internationalisation in HES, where the concept originated in the 1990s. I argue that despite efforts to expand its meaning, internationalisation continues to be perceived as a positive and unproblematic phenomenon and not as a transformation process involving complex power dynamics. This vision, I claim, forms the core of what I refer as ‘the dominant discourse of internationalisation’, which finds its origins in the intellectual and policy developments coming from the Global North. In the second part of the chapter, I discuss the family of approaches, methods, models and theories dealing with internationalisation in Science and Technology Studies (STS). In this case, I argue that STS scholars have only engaged with internationalisation indirectly and circumstantially, focusing mostly on the modes and patterns of internationalisation and less so on its complex transformative dynamics. I finish the chapter discussing the benefits of considering scientific internationalisation as a conceptual model of change to the same level as other renowned conceptual models in STS do (e.g. Mode 2, Triple Helix or Big Science). I explain how the study of scientific internationalisation as transformative process driven by tensions, can provide new insights on key theoretical discussions about knowledge production, diffusion and evaluation in science.

In Chapter 3, I continue exploring the meaning of scientific internationalisation in the life sciences and in Latin American STS. I first describe how the dominant discourse of internationalisation is present in social studies of the life sciences. I argue that this body of research tends to decontextualize the research communities they study, focussing on their international projection while ignoring the power dynamics present in them. Following this, I give an historical review of discussions around scientific internationalisation in Latin America. Internationalisation is a major topic of interest among Latin American STS scholars albeit approached from a distinct conceptual perspective. Here, discussions have revolved around the notions of dependency, asymmetry and development that continue to present days and which I discuss in detail. Lastly, I move on to examine contemporary visions of scientific
internationalisation in South American life sciences, collected via interviews I conducted with researchers from Argentina, Chile and Uruguay. As a result of this analysis, I present a ‘contextualised’ definition of scientific internationalisation of South American life sciences that contrasts with descriptions of the life sciences found in mainstream STS.

In Chapter 4, I present the research design of this thesis that uses the model zebrafish as a case study. I discuss first how model organisms have been used in STS to study social dynamics of science. I then review various features of the zebrafish model that make it a unique case to study transformations produced by internationalisation dynamics in South America. Following this, I examine the implications, limitations and opportunities of combining methods in STS. I argue that the study of scientific internationalisation requires insights from both quantitative and qualitative methods, which in turn demands a discussion of the extent to which a bridge between these two epistemic traditions can be built in STS. I finish this chapter introducing the methods of data collection I use in the thesis, i.e. interviews, bibliometrics and the Social Network Approach (SNA).

In Chapter 5, I investigate how dynamics of internationalisation intervened in the construction of zebrafish as a model organism. I begin the chapter discussing relevant concepts developed by the STS literature on model organisms. I address the limitations of these studies, explaining how they tend to ignore internationalisation dynamics in their analyses, which often take them to ‘un-problematize’ the collaborative ethos of model organism communities. Based on this, I then review the history of standardisation of the zebrafish as a model organism. I discuss how various internationalisation dynamics played an important role in its construction as a genetic tool and in the formation of the early zebrafish international community. I describe the trajectory of George Streisinger, the researcher who developed a technique to produce zebrafish mutants in the early 1980s, as well as the post-war context in which he developed his research. I then discuss the first international meetings on zebrafish research that established the structure of the early zebrafish community and the infrastructures envisaged to support the exchange of resources globally; namely the Zebrafish International Resource Center (ZIRC). I explain how the ZIRC gave the University of Oregon – where Streisinger developed his research on zebrafish – an authoritative voice in defining what counts as relevant zebrafish research and in delineating the material conditions laboratories worldwide must comply with to access
the model. Difficulties of sending fishes through formal channels such as the ZIRC, however, prompted the development of alternative practices based on informal networks of resource exchange. I finish the chapter discussing the experiences of South American zebrafish researchers, aiming to unpack dynamics of dependency and asymmetry present in practices of resource exchange, and the barriers and reactions to international infrastructures built to support these exchanges.

In Chapter 6, I study the role played by distinct collaborative networks in the diffusion of zebrafish as a model organism in Latin America and in other scientific regions from 1996 onwards. This was a crucial year in the history of zebrafish research as the results of the first random mutagenesis screens were published in a special issue of the scientific journal *Development*. Collaborative networks are thought to have facilitated the spread of zebrafish research across the spaces of scientific practice from then on. To study this, I use SNA techniques that allow me to observe the extent to which access to networks of experienced users of the model, presumably located outside the local milieu, is a factor that explains the diffusion of the zebrafish in a peripheral regional community such as Latin America. My analysis is based on the concept of *network exposure*, common in network diffusion models, and which is a proxy to measure the influence of collaborative networks upon behaviour change. In addition, I present a methodology I especially developed that allows me to incorporate the geographical dimension in this analysis and observe the influence of different spatial collaborative networks (i.e. international, regional and national) in explaining the adoption of zebrafish as a model organism. In the last part of the chapter, I take a closer look at the meaning of ‘exposure’ from the perspective of South American zebrafish researchers to better understand the role of international collaboration in this diffusion process. My analysis of co-authorship networks at the institutional level expanding over the 1996-2016 period shows that adoption behaviour of zebrafish in science is explained by exposure to a combination of national and international collaborative networks where direct collaboration with a small share of experienced national collaborators seems to act as a key driver of diffusion. For its part, the qualitative analysis of interviews further revealed that exposure to networks of international collaborators constitutes a practice of approximation to more advantageous material structures and less so to geographically concentrated novel knowledge.
In Chapter 7, I explore the relationship between internationalisation and the notion of ‘excellence’ in zebrafish research. I begin the chapter explaining how in the world of model organism research, excellence is commonly understood as actively contributing to knowledge infrastructures, including livestock centres and digital/genomic databases, thus helping to diffuse these models within and outside their scientific communities. However, the mechanisms by which internationalisation dynamics intervene in shaping this notion are still unclear. In this chapter, I study, on the one hand, practices of biological data curation taking place at the Zebrafish Information Network (ZFIN), the zebrafish international online database. I show how biocuration practices in ZFIN reproduce the existing uneven structure of knowledge diffusion and circulation in science based on publications in mainstream scientific journals. I further explain that because of this, Latin American zebrafish researchers’ visibility within the ZFIN echoes their previous visibility within the global publication-based system. I then study how international mobility – a key practice of scientific internationalisation – interacts with researchers’ contributions and visibility within the zebrafish database. Using bibliometric data, I reconstruct the mobility trajectories of zebrafish researchers, from Latin America and other world regions and I classify them using a taxonomy that distinguishes between types of international mobility events (Robinson-Garcia et al. 2019). As in Chapters 5 and 6, I combine this quantitative analysis with a qualitative analysis of interviews with South American zebrafish researchers. Results show that international mobility plays a key role in boosting researchers’ contributions to the community’s database in the form of curated annotations and it constitutes a critical mechanism for South American zebrafish researchers to access resources directly associated with the notion of research excellence including publications, research infrastructures and fish stocks.

Chapters 8 and 9 contain the final reflections of this research project. In Chapter 8, I present an overview of the findings of the thesis and I discuss my contributions to theoretical discussions around the concept of scientific internationalisation as well its relation to the study of scientific communities, knowledge diffusion process and the construction of the notion of research excellence in model organism science. In Chapter 9, I share my final reflections on the combination of methods in STS and the future of policies and studies of internationalisation.
A brief note on ‘geography’

It does no take an attentive reader to notice that while the focus of my research lies in ‘South America’, already in this introduction and throughout the rest of the thesis I also make frequent use of the term ‘Latin America’. Needless to say, these are two rather different geographical circumscriptions: Latin America involves all Spanish and Portuguese speaking countries in the American continent, whereas South America only refers to those countries that lie below the Panama Canal. I am aware this choice may create confusion and it requires a much deeper discussion, which is beyond the scope of this thesis, but I nevertheless want to address it here briefly.

There is a tendency among scholars in South America to generalise the scope of their discussions to all the Latin American countries, and STS scholars are no exception to this custom. The so-called ‘Latin American School of Thought in Science and Technology for Development’ (aka ‘the School’), which I discuss in detail in Chapter 3, was made of various technologists and thinkers, mostly from South American countries, such as:

- Jorge Sábato, Amílcar Herrera, Oscar Varsavsky and Carlos Martínez Vidal (from Argentina),
- Helio Jaguaribe and José Pelucio (from Brazil),
- Osvaldo Sunkel (from Chile),
- Luis Javier Jaramillo and Fernando Chaparro (from Colombia),
- Máximo Halty-Carrère (from Uruguay),
- Francisco Sagasti (from Peru)
- Ignacio Avalos and Carlota Perez (see Marí 2018) (from Venezuela).

The work of this pioneering group of STS scholars developed in a context shaped by the industrialisation process that followed the end of War World II and the influence of Cold War geopolitics in Latin America through the spread of military dictatorships sponsored by the U.S. This scenario led many intellectuals in the social sciences of the time to adopt a ‘Latin American perspective’ in their analysis expressing, in most cases, a socio-political aspiration rather than a deliberated research design. As noted by Hernán Thomas (2010), the writings of the authors of ‘the School’ did not form a unified corpus of scholarly research. What unified them

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1 Another well-known case is the so-called ‘Latin American boom’ in literature.
instead was a predominance of normative aspects over analytical ones; a concern for political issues related to neo-colonialism and dependency, which they saw reflected in the scientific and technology transference process of that time (Arellano Hernández and Kreimer 2011b).

I think that this context can also help us to understand the use of the term ‘Latin America’ in their writings. It expressed the ‘rediscovery’ of a shared identity and a common fate in a period of intense political and economic turmoil and oppression. Though concerned with policy practice in each of their respective countries, these authors made frequent use of the term ‘Latin America’ to show that the challenges faced by say Argentinean researchers were similar to those faced by colleagues in Mexico, Brazil or Chile. This writing style certainly left a mark in future Latin American social sciences. The failure of the neoliberal program throughout the 1980s and 1990s brought again a sense of common fate that materialised in the coming into power of left-wing governments during the first decade of 21st century and with it, greater regional cooperation. At the same time, Latin American STS researchers increasingly adopted greater methodological rigor in their research. Though based on detailed case studies, contemporary STS scholars in the region have continued adding the label ‘Latin America’ in the titles of their papers and books and throughout their writings. While in many cases this is due to the choice of editors seeking to appeal to a larger group of readers often not familiar with Latin American issues, it also shows a line of continuity with the style of ‘the School’ and its concern with normative and political issues of Latin America as a whole.

I use the terms ‘South America’ and ‘Latin America’ in this thesis for similar reasons. As my fieldwork covered Argentina, Chile and Uruguay, I understand my findings can at best speak about internationalisation dynamics in South American life sciences. While I am aware that South America is a contrasting and heterogeneous region in itself – e.g. countries differ greatly in the size of their national scientific and technology systems or in the relative importance of private and public sectors – I also recognise these countries face a series of structural limitations (e.g. limited access to international centres of knowledge production, funding, research infrastructures, etc.) that go beyond the limits of the Panama Canal. In this sense, the quantitative techniques I use in this thesis allowed me to overcome the limitations of a qualitative research design and conduct large-scale research that not only includes Latin America but also other circumscriptions such as European, North American or Asia-
Pacific for comparative purposes. For its part, my qualitative analysis is based on the experiences of researchers I interviewed during the fieldwork. This helps me to bring back the focus to South America by providing a more detailed analysis of certain aspects left unclear by the quantitative analysis. Conducting mixed-method research therefore allows me to play with this ambiguity, which although I acknowledge it, I do not intend to resolve here.
Chapter 2: Making Sense of Internationalisation

It is quite certain that science cannot progress properly except by the fullest internationalism.

A.V. Hill (1933, 954)

Introduction

Hill’s opening quote to this chapter is extracted from an article published in *Nature* at a time when purges and political violence had begun striking German universities under the newly Nazi regime. The quote not only illustrates the deep concern of the Nobel laureate over the rise of fanatic nationalism across Western Europe at the time; it also works as a restatement of the long-held vision of science: its inherent *transnational character* and *solidarity*. While according to almost all accounts, science has always had an international dimension, the need to defend or promote its internationalism has not been exclusive of politically convulsive times. With the advent of globalisation (i.e. the higher, faster and more intense connectedness of countries since the second half of the 20th century), as science started to be perceived as an asset to compete in the global economy, internationalisation begun to be regarded as the means to increase economic growth and promote well-being and human development. Science, in other words, was to become *more internationalised*. But what does internationalisation actually mean? With the popularisation of internationalisation strategies since the 1990s, internationalisation has become a buzzword and a container concept that includes everything that relates to the ‘international’. Meanwhile, internationalisation has been losing its meaning (de Haan 2014; de Wit 2001).

In this chapter, I provide an overview on the phenomenon of internationalisation and of scientific internationalisation in particular. I describe how, despite recent developments in its conceptualisation, internationalisation continues to be perceived primarily as a positive and unproblematic phenomenon, and not as a *transformation process* involving complex power dynamics in education and science. This attitude, I claim, results mostly from intellectual and policy developments taking place in the Global North during the 1990s and early 2000s that have formulated the
dominant view of internationalisation we see in both academic and policy spheres today.

I start the chapter examining from a historical and spatial perspective the evolution of the concept of internationalisation in Higher Education Studies (HES) as it is in this field of research where the first and most vibrant discussions have been taking place since the 1990s. I notice how, even though recent definitions have broadened the concept, internationalisation continues to refer almost exclusively to European and U.S. contexts, ignoring global power dynamics. This unproblematic conceptualisation, by which internationalisation is regarded as a desired outcome and a tool to cope with the challenges of globalisation, forms the core of what I refer to as ‘the dominant discourse of internationalisation’.

In the second part of the chapter, I move on to review existing approaches, methods, models and theories in Science and Technology Studies (STS) that together form the corpus of what I have labelled ‘the social study of scientific internationalisation’. I describe how this rich body of research has only engaged with internationalisation studies rather indirectly and circumstantially, focusing mostly on the modes and patterns of internationalisation in science and less so on its complex transformative dynamics.

Lastly, after describing the tensions that surround the concept, I make the case for considering scientific internationalisation as a conceptual model that deals with transformation processes to the same level as other renowned conceptual models in STS do (e.g. Mode 2, Triple Helix or Big Science). Considering this, I finish the chapter discussing how the study of scientific internationalisation can provide new insights on key theoretical discussions involving dynamics of knowledge production, diffusion and evaluation in science. In short, I argue, in science studies, internationalisation demands attention in its own right.

Defining internationalisation

According to the Cambridge dictionary, internationalisation is defined as “the action of becoming or making something become international” (2020). The reason for selecting this dictionary entry as a starting point of my argument is to show that from a general point of view, the notion of internationalisation is connected to a transformation capacity. In fact, this transformative quality of internationalisation has been the subject of extensive scholarly debate over the last three decades, mostly
within North American and European HES. Throughout this time, new and related phenomena like globalisation and regionalism have emerged and have given place to various interpretations of internationalisation. Recently, it has been claimed that the internationalisation debate has reached maturity (Sanderson 2008; Knight 2011; de Wit 2011), illustrated by the scholarly efforts to produce a synthetic definition. But, while internationalisation has broadened its scope enough to become a container concept, tensions remain over the power dynamics that continue to be ignored in the definition of internationalisation. In the dominant discourse, I note, internationalisation is mostly defined by the Global North as a phenomenon to which a highly positive connotation is frequently assigned. Because of this, internationalisation policies are designed to develop, augment or even protect the international dimension of education and research activities.

**Internationalisation of higher education**

**From fragmented concepts to a synthetic definition**

The vast majority of the relevant literature on internationalisation is related to higher education. The university is considered the one institution to have been historically international and the most important global force for the production and circulation of knowledge (Altbach 1998; Scott 2011). However, as most universities originated in the 18th and 19th centuries, besides having an international vocation, universities have also a clear national orientation and function (de Wit and Merkx 2012). Because of the university’s binary nature, it is no wonder that the most vibrant discussions about internationalisation are to be found in HES.

Initially, discussions in this field revolved around the term ‘international education’ that sprung up to denote a concern with practice and implementing education policy as opposed to the term ‘comparative education’, which indicated more an scholarly interest in explaining why educational systems vary across countries (Epstein 1994). According to de Wit (2013), both the applied character and the related notion of practice and policy implementation have been historically present in the discourse on international education. This has expressed, for instance, in the names of the key associations dealing with international cooperation and exchange, such as the Institute of International Education (IIE), the Association of International Educators (NAFSA) or the European Association for International Education (EAIE), among several others institutions across the world (p.18-19).
In addition, de Wit (2001) notes that it is not clear when the term transitioned from ‘international’ to ‘internationalisation’ of (higher) education (p.104-109). However, what we do know, he later claim, is that “it is only in the 1990s that the term ‘internationalisation’ really takes over from ‘international education’ as describing the different ways the international dimensions in higher education are taking shape” (de Wit 2013, 19 my emphasis). As I describe in the next section, while these ‘different ways’ express distinct and, in some cases, opposite interpretations and policy strategies, together they form a dominant discourse that understands internationalisation as a positive and desired outcome.

In terms of the evolution of the concept in HES, Haijing de Haan (2014, 243–45) identifies at least three clear phases from the early 1990s until present days (see table 1). A first phase identified by de Haan involves a shift from an ‘activity-focused’ to a ‘strategy-focused’ perspective in the conceptualisation of internationalisation. In the early stages, de Haan explains, internationalisation was defined in terms of the multiple activities that had an international dimension, including short-term programs of student and staff exchange and cooperation. Gradually, with the increasing complexity of international activities, internationalisation started to gained importance to the point that strategic management was introduced to the internationalisation process. Internationalisation, in other words, became something that could managed and therefore controlled.

**Table 1.** Evolution of the definitions of internationalisation (source: de Haan 2014)

<table>
<thead>
<tr>
<th>Scholar</th>
<th>Year</th>
<th>Level of focus</th>
<th>Meaning of internationalisation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arum and van de Water</td>
<td>1992</td>
<td>Institutional</td>
<td>Activities</td>
<td>“the multiple activities, programs and services that fall within international studies, international educational exchange and technical cooperation” (p.202)</td>
</tr>
<tr>
<td>Knight</td>
<td>1994</td>
<td>Institutional</td>
<td>Process</td>
<td>“the process of integrating an international and intercultural dimension into the teaching, research and service functions of the institution” (p. 7)</td>
</tr>
<tr>
<td>Rudzki</td>
<td>1995</td>
<td>Institutional/sectoral</td>
<td>Defined feature</td>
<td>“a defining feature of all universities, encompassing organisational change, curriculum innovation, staff development and student mobility, for the purposes of achieving excellence in teaching and research” (p. 421)</td>
</tr>
<tr>
<td>Author</td>
<td>Year</td>
<td>Type</td>
<td>Definition</td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>------</td>
<td>---------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>van de Water</td>
<td>1997</td>
<td>National</td>
<td>“any systematic effort aimed at making higher education responsive to the requirements and challenges related to the globalisation of society, economy and labour markets” (p. 18)</td>
<td></td>
</tr>
<tr>
<td>Ellingboe</td>
<td>1998</td>
<td>Institutional</td>
<td>the process of integrating an international perspective into a college or university system” (p.199)</td>
<td></td>
</tr>
<tr>
<td>Söderqvist</td>
<td>2002</td>
<td>Institutional</td>
<td>“a change process from a national higher education institution to an international higher education institution leading to the inclusion of an international dimension in all aspects of its holistic management in order to enhance the quality of teaching and learning and to achieve the desired competencies” (p. 29)</td>
<td></td>
</tr>
<tr>
<td>Knight</td>
<td>2003</td>
<td>Sectoral/</td>
<td>“the process of integrating an international, intercultural or global dimension into the purpose, functions or delivery of postsecondary education”(p. 2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>national</td>
<td>“internationalisation can best be defined as the totality of substantial changes in the context and inner life of higher education relative to an increasing frequency of border-crossing activities amidst a persistence of national systems”(p. 22)</td>
<td></td>
</tr>
</tbody>
</table>

De Haan identifies a second evolution which is the broadening from the institutional level to the sectoral, national and regional levels of higher education systems. She observes that while early definitions of internationalisation focused on the capacities of institutions of integrating the international dimension into educational activities (e.g. Knight 1994), later studies placed emphasis on the impact of internationalisation on the whole higher education system that could reach sectoral, national or even regional levels. Internationalisation thus transformed into a multi-level phenomenon.

The third and last evolution in the definition of internationalisation identified by de Haan is the transformation of the study of internationalisation from fragmented studies to a unified field of research. In this transformation, the notions of ‘process’ and ‘integration’, she observes, are fully embraced and remain as the most important elements of the definitions of internationalisation in HES.
Overall, de Haan notices, these evolutions eventually led to a synthetic view of internationalisation, giving the concept its ultimate transformative quality, expressed in Jane Knight’s famous definition:

Internationalisation at the national, sector, and institutional levels is defined as the process of integrating an international, intercultural, or global dimension into the purpose, functions or delivery of postsecondary education (Knight 2003, 2 my emphasis).

Knight further explains what the different components of the above synthetic definition imply in practical terms. The term ‘process’, she claims, is deliberately used to convey that the concept of internationalisation has a developmental quality (Knight 2004, 11). The concept of ‘integration’ is specifically used to denote “the process of infusing or embedding the international and intercultural dimension into policies and programs to ensure that the international dimension remains central, not marginal, and is sustainable” (Knight 2003, 3). The ‘international’, ‘intercultural’, and ‘global’ dimensions, she continues, are used as a triad. Internationalisation is synonymous with social relations between nations, countries or cultures, even within countries. This provides a social network perspective to the concept, now understood as relational phenomenon.

The latest development in the definition of internationalisation has been the introduction of the terms “cross-border education” (Knight 2006) and “internationalisation at home” (Nilsson 2003). Both terms represents to some extent a broadening of the concept of academic mobility beyond students and staff. In the case of “cross-border education”, the concept extends the notion of mobility to include programmes, providers (including institutions and companies), projects and policies in a context driven by a growing demand of higher and continuing education (Knight 2006, 346). Because of the amplified interest on international academic mobility, for its part, the ‘at home’ concept has been developed to emphasise the importance of the international and intercultural dimension in any educative activity with the exception of outbound student mobility (Knight 2013, 85; Nilsson 2003).

Altogether, these developments show the intellectual efforts to define a complex phenomenon that throughout the years became more and more prominent in the higher education policy agenda. Internationalisation eventually became to be regarded as a desired outcome that could be increasingly managed. As I discuss next,
this vision results mainly from intellectual and policy paradigms coming from the Global North.

The dominant discourse of internationalisation

Goldman (2001) notes that while internationalisation implies the existence of nation-states, studying internationalisation is exploring a process where “distinctive units lose their distinctiveness” (p. 9). This nation-state erosion or deficit comes in different formats and results from the application of different policies of internationalisation in Europe and North America. Yet despite the different policy paradigms that inform the rationale of their policies, the European and North American take on internationalisation share an uncritical view of the phenomenon. Altogether, the dialectical tension between mayor policy paradigms (e.g. internationalisation and transnationalisation) as well as the different projects of regional integration taking place in both sides of the North Atlantic during the 1990s and early 2000s, contributed to form the core of the dominant discourse of internationalisation.

As I explained previously, the term ‘internationalisation’ emerged in the higher education literature in the 1990s. Not surprisingly, this was a key period for higher education worldwide as various internationalisation reform strategies were set in motion seeking to cope with the challenges and opportunities raised by globalisation (de Wit and Merkx 2012). In general, the literature describes a global debate throughout this period between two policy strategies to carry out such reform. Sustained by different theoretical assumptions and policy objectives, each strategy advocated contrasting roles of the nation-state as a regulator of education services.

On the one hand, based on an intergovernmental approach and led by the United Nations Educational, Scientific and Cultural Organization (UNESCO), the internationalisation approach to higher education sought the promotion of cooperation and networking activities between nation-states, who were thought to keep domestic control of education services by defining rules for suppliers and consumers. On the other hand, the World Trade Organization (WTO), based on a neoliberal approach that materialised in the General Agreement in Trade and Services (GATS), propounded a process of transnationalisation, which affected various services sectors including education. Moreover, in this transnationalisation approach, nation-states were to be detached from their traditional role as regulators of domestic educational
activities, to avoid protecting national suppliers from foreign competition (Knight 1999; Coraggio 1995; Verger 2013; Botto 2015; 2016).

According to Botto, this global debate also arrived at the regional level through the so-called ‘New Regionalisms’; a new wave of regional integration processes that began in the 1990s and which mirrored, to a large extent, the transnationalisation processes occurring at the global level within the framework of the WTO. Nevertheless, Botto notes, the literature on regionalism and higher education is divided in terms of how alternative and innovative these processes were when compared to the ideas that came from the global arena. In Europe, the shift towards internationalisation was very much stimulated by the Framework Programme and the Erasmus mobility scheme of the European Commission, seeking to increase cooperation between member states in education and promote regional integration further (see de Wit 2013). Moreover, according to Van den Besselaar et al. (2012), policies developed at the European level have not only played a major role in setting and disseminating internationalisation as a policy objective to be achieved, but they have also given rise to a distinct form of internationalisation: Europeanisation. The latter constitutes a restricted form of international standing, which is strongly affected by policies that aim to effectively integrate Member States’ national education and research agendas, while promoting European integration.

In North America, contrary to the European case where the reform process laid in the hands of governments, the internationalisation agenda of higher education was driven by the private services sector who lobbied in favour of transnationalisation (Botto 2015). Pushed forward by the North American Free Trade Agreement (NAFTA) – a closed-type arrangement limited to the free movement of goods, services and investments involving the U.S, Canada and Mexico –, transnationalisation meant the application of neoliberal reform policies in higher education. However, Botto (2016) affirms that these New Regionalisms ended up creating a regional space for higher education focused on student mobility programs and degree accreditation with their own regional practices and norms, and which reflected in the strategies of internationalisation and transnationalisation (p.167-168).

It should be noted that the conceptualisation of internationalisation as a set of strategies, programmes and policies implemented to respond to globalisation derives from the idea that the forces of globalisation are beyond the control of single institutions (Altbach 2006; Altbach, Reisberg, and Rumbley 2010). Examples of these
greater forces are use of English as the dominant language of communication or the emergence of an international knowledge network. However, the literature on higher education often stresses the relationship between the concepts of internationalisation and globalisation as rather complex (Knight 2004, 11; Teichler 2004; Scott 2005; Altbach 2006; H. de Wit 2013). For some the relationship between globalisation and internationalisation is best described as symbiotic. As noted by Jane Knight (2004): “internationalisation is changing the world of higher education, and globalisation is changing the world of internationalisation” (p.5). Similarly, Maringe and Foskett (2013) argue that internationalisation and globalisation are reciprocal processes. The growth of international student mobility, which may result from an institutional strategy, they note, contributes the further intensification of globalisation. At the same time, intensifying curriculum internationalisation processes can contribute to increase the value of educational products and therefore help to increase student mobility.

For others, however, the distinction between globalisation and internationalisation is rather normative. Frans van Vught et al. (2002), for instance, note:

In terms of both practice and perceptions, internationalisation is closer to the well-established tradition of international cooperation and mobility and to the core values of quality and excellence, whereas globalization refers more to competition, pushing the concept of higher education as a tradable commodity (p. 17).

Uwe Brandenburg and Hans de Wit have warned that these types of definitions often lead to a constructed antagonism between internationalisation and globalisation where internationalisation is considered as synonymous with ‘doing good’ and globalisation as ‘bad’. This, they explain, makes people less inclined to question the nature of internationalisation or acknowledge that activities more related to the concept of globalisation (e.g. the commodification of higher education) are increasingly executed under the flag of internationalisation (Brandenburg and de Wit 2015, 16–17).

According to Teichler (2004), the complexity of the relationship between globalisation and internationalisation in higher education has often led to the substitution of the term ‘globalisation’ for ‘internationalisation’, resulting also in a shift of meanings. He notices that:
“[n]o interest is paid anymore to whether the phenomena are linked to a blurring or vanishing of borders. Rather, the term tends to be used for any supra-regional phenomenon related to higher education […] and/or anything on a global scale related to higher education characterised by market and competition” (p. 23).

In light of the growing importance of internationalisation as a policy objective, de Wit (2001) notices that “as the international dimension of higher education gains more attention and recognition, people tend to use it in the way that best suits their purpose” (p.14). By matching internationalisation to different rationales and objectives, these policies hence became materialisations of the different meanings of internationalisation. However, I argue that despite these variations, a dominant discourse of internationalisation can be identified. This mostly Global North discourse is built around an uncritical view of the phenomenon of internationalisation that transcends the dialectical tension between the policy paradigms of internationalisation and transnationalisation, on the one hand and between internationalisation and globalisation, on the other. Even though they propounded different meanings, in each of the strategies discussed above, internationalisation was conceived as a desirable outcome. Whereas in Europe the *Europeanisation* of higher education was designed as a key driver of European integration, in North America *transnationalisation* was supposed to increase the region’s competitiveness at the global stage. However, as Brandenburg and de Wit (2015, 16) explain, in both cases internationalisation became *the main objective*. The international dimension of higher education systems therefore was something that *needed to be increased* through more mobility, collaboration, recruitment, with more or less state intervention, and so on, in order to cope with the challenges and opportunities raised by globalisation.

**Critical perspectives on internationalisation of higher education**

Recently, some of the most prominent voices in this debate have started to call for a critical reflection on the changing concept of internationalisation. Concerned about the present devaluation of the concept, these new critical perspectives begun addressing some of the most common misinterpretations about internationalisation that result from the instrumental approach to internationalisation discussed earlier.

For instance, Knight (2011) discusses five myths of internationalisation:

1. Considering foreign students as internationalisation agents.
2. Equating international reputation with quality.
3. Believing that the greater number of international agreements or network memberships a university has the more prestigious and attractive it is to other institutions and students.
4. The tendency to acquire more international accreditation to internationalise an institution.
5. Assuming that the purpose of a university's internationalisation efforts is to improve global brand or standing.

Similarly, de Wit (2015, 6–7) describes nine misconceptiones whereby internationalisation is regarded as a programmatic goal. These include:

1. Internationalisation is education in the English language.
2. Internationalisation is studying or staying abroad.
3. Internationalisation equals an international subject.
4. Internationalisation implies having many international students.
5. Having a few international students in the classroom makes internationalisation into a success.
6. There is no need to test intercultural and international competencies specifically.
7. The more partnerships, the more international.
8. Higher education is international by nature.
9. Internationalisation is a goal in itself.

For de Haan (2014), however, this newly emerging view of misconceptiones is a central characteristic of the synthetic concept of internationalisation (or as I have described it, of the ‘dominant discourse of internationalisation’) by which interpretations are cherry-picked to keep the container consistent. In turn, de Haan adopts Callan’s assertion that interpretations of internationalisation do not develop in a vacuum, but are affected by the organisation and consciousness of professional practice (Callan 2000). Hence, for de Haan (2014), such ‘misinformed’ pieces are not misconceptiones or misinterpretations, but perceptions that are significant because they represent how people working in higher education are making sense of internationalisation (p. 254).
Perhaps the most important reflection among the recent critical perspectives in HES refers to the reasons for constantly rethinking the concept of internationalisation. For instance, Hans de Wit (2013) criticises the emergence of new labels such as ‘mainstreaming’, ‘comprehensive’, ‘holistic’, ‘integrated’ and ‘deep’ internationalisation that, in his view, do not help bring the concept a step forward. Instead, he argues, that we not only need to look at the misconceptions, but also acknowledge that the (1) discourse of internationalisation does not always meet the reality; (2) move away from a western, neo-colonial concept and incorporate views coming from developing countries; (3) ensure that no single approach or paradigm dominates the discourse; and (4) see internationalisation not as a goal in itself, but as a means to enhance the quality of education and research (Jones and de Wit 2012; de Wit 2013). For now, however, this is still far from becoming the dominant discourse in HES.

Internationalisation of science

So far, I have described the evolution of the concept of internationalisation in higher education. But what about internationalisation of scientific research? Unlike HES, in STS there has not been a collective scholarly debate about the meaning of scientific internationalisation (Woldegiyorgis, Proctor, and de Wit 2018), yet internationalisation has been and continues to be a topic of interest in this field. In this second part of the chapter, I analyse how the phenomenon of internationalisation has been analysed in STS from both theoretical and empirical perspectives. I first discuss the intellectual parallels that can be drawn with HES regarding the conceptualisation of internationalisation, and I explain the research topics where STS scholars have focused on. I then review existing approaches and methods that together form the corpus of what I have labelled ‘the social study of scientific internationalisation’.

Following this, I make the case in favour of treating scientific internationalisation as a model for explaining transformation in science. In doing so, I discuss how the study of internationalisation can provide new insights in key theoretical discussions involving dynamics of knowledge production, diffusion and evaluation in science.
Scientific internationalisation

The literature on internationalisation is dominated by HES and vice versa, internationalisation is a dominant topic in HES. Certainly, the literature on higher education internationalisation overshadows both in depth and numbers the literature about scientific internationalisation. Nevertheless, some parallels with the intellectual developments in HES described earlier can be drawn. I have identified at least three elements that can be subject to comparison between HES and STS regarding the concept of internationalisation: (1) the geographical paradox of science; (2) the incidence of globalisation; and (3) the emergence of critical perspectives on scientific internationalisation.

The geographical paradox of science

The evolution of the concept of internationalisation in HES has been marked by the dual nature of the university. That is, an international and global vocation on one side and a clear national orientation and function on the other. In science, a similar dichotomy can be found. Science studies have noted that scientific knowledge is geographically paradoxical (Livingstone 2003). This means that, while science claims to produce universal knowledge, at the same time we know science significantly depends on local contexts. A sociological concern then emerges; how do knowledge transactions occur between the places of science? (Shapin 1998). Within scientometrics, the quantitative ‘branch’ of STS, spatial scientometrics has addressed this question by observing spatial patterns in scientific interactions via research outputs. In their now seminal paper, Frenken, Hardeman, and Hoekman (2009) proposed the concept of ‘spatial proximity’ (and its different dimensions) as the theoretical starting point for spatial scientometric research, which at the time was described as rather fragmented. The novelty of the proximity concept included the idea that being proximate in one dimension (e.g. geographical) allows distance in another dimension (e.g. cognitive) (Liscovsky Barrera 2019c).

Almost all the consulted STS literature in this project begins by acknowledging the international character of scientific practice. Science is by definition international. Evidence of this is that scientific practice has historically trespasses national borders. Beaver and Rosen (1978) for instance, investigated the professional origins of scientific co-authorship and traced back international collaborative linkages to as early as the 19th century. They concluded scientific internationalisation is correlated with
increasing professionalization of science. For its part, international mobility stretches even further back in time, to the early days of medieval university when research was conducted internationally through the tradition of the “wandering scholar” (Welch and Denman 1997; Scott 2011; Woldegiyorgis, Proctor, and de Wit 2018). At the same time, STS researchers have also long recognised the significance of local contexts for the production of knowledge (Somsen 2008). Not only locality matters in science, but also internationalisation does not imply the de-nationalisation of science. Scholars, for instance, have noted that in science funding remains mainly national and allocated to national priorities, career trajectories are nationally-based and the institutional framework is still mainly national (Patel and Pavitt 1991; Crawford, Shinn, and Sörlin 1993; Zitt and Bassecoulard 2004). These are the features that explain the relevance of the National System of Innovation from an academic and policy perspective (Lundvall 1992; Freeman 1995). Overall, like higher education, scientific internationalisation is shaped by this spatial tension.

**The incidence of globalisation on scientific practice**

Whether or not scientific internationalisation is a new phenomenon, a major point of agreement in the literature is that globalisation has increased and intensified the international character of scientific practices. Some of examples of these transformations include (1) the growth of international collaborative networks induced by new forms of communication and reduction of travel costs (Wagner and Leydesdorff 2005; Waltman, Tijssen, and Eck 2011); (2) the rise of world university rankings and the ensuing global competition for talent and resources (Hazelkorn 2011); (3) the use of English as a global language of scientific communication (Ammon 2001; Ferguson 2007), and (4) the appearance of new forms of science policy-making and funding schemes at the supranational level, which have become an important source of coordination and funding for the internationalisation of research (Glänzel, Schubert, and Czerwon 1999; Hoekman, Frenken, and Tijssen 2010). These are just a few of the many indicators frequently used by scholars to show the impact of globalisation on the internationalisation of research. As such, like in HES, it is common to find in the STS literature an interchangeable use of both terms. However, while the tendency to treat globalisation and internationalisation as synonymous in HES was framed within an extensive debate about the complex relationship between both terms, in STS only handful of scholars have established a normative distinction between internationalisation and globalisation (Hakala 1998;
In science studies, internationalisation is mostly seen as part the general incidence of globalisation, and which leads to greater research quality, cooperation, sharing of resources and costs, visibility and knowledge diffusion (Dasgupta and David 1994; Licha 1996; Katz and Martin 1997; RICYT 2007; De Filippo, Casado, and Gómez 2009).

**Critical perspectives on scientific internationalisation**

In spite of the lesser amount of discussions around the concept of scientific internationalisation, there have been some scholars that, while not necessarily discussing the concept of internationalisation, have called into question the taken for granted nature of related notions such as ‘internationalism’ and ‘universalism’. For instance, according to Somsen (2008), while the inherent international character of scientific practice can be rejected, its power of self-representation cannot be denied. That is, science might not be universal or international per se, but scientists often view it in such terms. Accordingly, Somsen shows how, throughout history, concepts like ‘universal’ or ‘international’ are simply codewords for ‘Western’ or ‘European’. Similarly, Hakala (1998) notes that although there is a clear increase in transnational and multinational activity, it would be misleading to say that internationalisation of science equals globalisation of science (p. 52). Following Leclerc and Gagné (1994), Hakala argues it would be more apt to speak about continentalisation or westernisation as the vast majority of these increased interactions involve world regions which have traditionally shared strong links (e.g. Europe and North America). As with HES, these critical perspectives show how the dominant understanding of internationalisation in science is, above all, a Global North construct. This is not say that there are no critical perspectives in STS with regards to the phenomenon of internationalisation (or globalisation). However, as I will discuss later, these perspectives deal more with issues related to knowledge production and diffusion in science – where internationalisation is certainly treated as a key dimension – and not with the concept of internationalisation itself.

**Modes and patterns of scientific internationalisation**

In STS, the lack of discussion on the concept of internationalisation has often resulted in scholars taking for granted the nature of scientific internationalisation (Woldegiyorgis, Proctor, and de Wit 2018). Nevertheless, a great deal of work in STS
has been devoted to study the different modes and patterns that emerge when internationalisation is observed from a distance. These studies show that in science internationalisation expresses in various modes or practices, of which cross-national mobility and collaboration are some, if not the most, recognisable. Both practices constitute major drivers of knowledge production and diffusion, and scholars have widely explained their growth as a consequence of globalisation (Glänzel, Debackere, and Meyer 2008; Franzoni, Scellato, and Stephan 2012; Auriol, Misu, and Freeman 2013).

**Modes: mobility and collaboration**

Scientific mobility is a concept that comprises geographical, institutional, sectoral and career-based movements that can have significant consequences for individual researchers and the research system as a whole (Fernández-Zubieta, Geuna, and Lawson 2015). Mobility facilitates the creation and diffusion of knowledge, particularly tacit knowledge, which is often transmitted through direct personal interactions (Jaffe, Trajtenberg, and Henderson 1993; Audretsch and Feldman, 1996; OECD 2005; 2010; Basri et al. 2008). Moreover, travelling researchers ensure that the knowledge they have acquired is available in other distant locations (often in their respective home countries) and act as key brokers maintaining networks that facilitate continuing knowledge exchange and collaboration (Appelt et al. 2015; Rodrigues, Nimrichter, and Cordero 2016). Various studies have measured the exponential growth of international mobility worldwide and have concluded that, in the context of globalisation, mobility is an important positive factor for knowledge production and diffusion that countries should embrace as a major policy objective (De Filippo, Casado, and Gómez 2009; Basri et al. 2008; OECD 2001; 2013; Wagner and Jonkers 2017; for a detail review see Gureyev et al. 2020).

Similarly, the growth of international collaboration is well documented in the literature (Georghiou 1998; Newman 2001a; Persson, Glänzel, and Danell 2004; Glänzel and Schubert 2005; Leydesdorff and Wagner 2008; Waltman, Tijssen, and Eck 2011). Some scholars have argued that international collaboration in science constitutes a different type of communication network than national systems with their own internal dynamics. While nations have policies and institutions that mediate scientific communication, the international collaborative network exists primarily as a self-organizing system (Hicks and Katz 1996; Wagner and Leydesdorff 2005; Wagner 2008). International collaboration also takes place in a variety of forms. It can involve
individuals, research groups, institutions, sectors or even countries who come together to co-author a scientific paper, participate in a large-scale research project or simply exchange resources such as infrastructures, protocols or training. For this reason, Katz and Martin (1997) argue that scientific collaboration is a fuzzy concept open to negotiation. Others like Sonnenwald (2007) and Olechnicka, Ploszaj, and Celińska-Janowicz (2018) argue that a key component of scientific collaboration is the existence of a common goal, which allows differentiating collaboration from other forms of interaction in science. Additionally, other authors had distinguished between strong and weak modes of collaboration on the one hand – the former is directly associated to a specific research process; the later indirectly associated or independent — (Laudel 2002) as well as between complementary or integrative depending on the degree of interaction and interdependence between collaborators (Hara et al. 2003).

**Patterns of internationalisation**

Studies of international mobility and collaboration have also provided insights about patterns of internationalisation and the structure of the global scientific system. For Gorniztka et al. (2003, 10), despite the long history of internationalisation, a distinction can be made between ‘traditional’ and ‘emerging’ patterns of internationalisation. The former are related to the mobility of students and researchers, a practice that is strongly connected to ‘informal’ institutions such as scientific disciplines. The underlying rationales of this traditional form of internationalisation are academic, economic, military, social or cultural. In turn, emerging patterns of internationalisation are more routinized, institutionalised and formalised at different levels (i.e. institutional, national and supranational), and dominated by economic rationales and market control mechanisms.

Well-known examples of traditional forms of internationalisation are the so-called Big Science projects like the European Organization for Nuclear Research (CERN), the European Molecular Biology Laboratory (EMBL) and international institutions oriented to science policy like the Organisation for Economic Co-operation and Development (OECD) and UNESCO. In addition, Gorniztka and colleagues (Ibid) consider the transnationalisation reform policies of the 1990s (see previous section on the dominant discourse of internationalisation) as examples of emerging forms of internationalisation. In practice, however, the authors acknowledge that these new forms are more difficult to identify because they have become a more generic
characteristic of research and higher education (Ibid, 29). For Johnathan Adams (2013), in turn, the intensity and overarching presence of ‘new’ patterns of internationalisation can be observed in the rise of international collaboration in science. For Adams, this indicates that we have entered ‘the fourth age of research’, which constitutes a progression from the ages of the individual, the institutional, and the national, which determined the way research was conducted previously.

Other scholars have described different patterns of internationalisation across scientific disciplines. Kyvik and Larsen (1997) and Hakala (2002), for instance, analyse patterns of internationality across ‘hard’ and ‘soft’ sciences as well as ‘pure’ and ‘applied’ research fields. The higher international activity of hard and applied scientific disciplines according to these studies, is explained by a mixture of factors including the ‘universal’ nature of their topics as well as the existence of reward structures and publishing traditions oriented to international and English-spoken scientific journals, which are often associated with greater research quality. Moreover, several works have found the number of multi-national co-authorships – i.e. a proxy to measure international collaboration – to be greater in applied, experimental and resource-intensive fields such as the life sciences, chemistry and experimental physics compared to engineering and agriculture or other more theory-oriented such as mathematics (Newman 2001a; Glänzel and de Lange 2002; Abt 2007; Wuchty, Jones, and Uzzi 2007; Mattsson et al. 2008; Gazni, Sugimoto, and Didegah 2012). Similar trends have also been found in practices of international mobility (Rothwell 2002; Rodrigues, Nimrichter, and Cordero 2016).

Lastly, when analysing international collaboration and mobility practices, scholars have described the formation of core-periphery patterns of internationalisation (see Schott 1991). For Olechnicka and colleagues (2018), the collaborative turn in science described by Adams (2013) presents a global hierarchical structure that results from the international division of scientific labour. Such division, they observe, produces core-periphery dynamics in the international network of scientific collaboration illustrated by the uneven access to facilities, resources, knowledge and expertise (Ibid, 45-52). In studies of scientific mobility, much of the literature focuses on the famous ‘brain drain’ phenomenon; a term coined by the Royal Society of London in the 1960s to describe the massive migration of British engineers and scientists to the U.S. (Rhode 1991; RS 2011). Nowadays, the term refers more broadly to the unidirectional migration of skilled workers from less
developed to more developed countries or regions (Fernández-Zubieta, Geuna, and Lawson 2015).

**The social study of scientific internationalisation**

In what follows, I discuss how scientific internationalisation is actually studied from an STS perspective. The family of theoretical perspectives and the different epistemological tools together form what I have labelled ‘the social study of scientific internationalisation’. In this sense, this section constitutes an attempt to compile and synthetize the large variety of existing approaches and methods that exist in STS to study the social dynamics of scientific internationalisation.

**Theoretical approaches**

Approaches to study dynamics and modes of scientific internationalisation can be divided into four large categories: functionalist, rational-choice, network and constructivist. I made this classification following the review conducted by Gornitzka et al. (2003). However, while their review focuses on aspects related to research evaluation, in my case I focus on the social dynamics of scientific internationalisation. In particular, I attended to the common focus that a wide variety of social studies of science, dealing with the phenomenon of internationalisation, share in various degrees. I explain briefly each approach, its connection with the concept of internationalisation and I provide references to key studies in STS.

**Functionalist approach: internationalisation as an organisational output**

According to the functionalist approach, actors of the scientific social system (e.g. scientists, students and policy-makers) are organisationally constrained and constituted actors. In light of this, policies, organisational structures and supranational environments are thought to have a direct impact on practices of scientific internationalisation. In the STS literature, functionalist studies deal almost exclusively with research organisations and their relationship with scientific collaboration. Key studies include Crow and Bozeman’s (1987) typology of research and development (R&D) laboratories, Leydesdorff and Etzkowitz’s (1998) ‘Triple Helix’ metaphor and Shrum, Genuth, and Chompalov’s (2007) classification of structures of collaboration. In general, studies of scientific collaboration describe how the com mingling of scientists from various disciplines, nationalities and institutions constitutes a novel feature in the social organisation of science (Knorr-Cetina 1999).
Rational-choice: internationalisation as an individual output

As an individual-based approach, rational-choice assumes actors of the scientific social system to be autonomous agents driven by cost-benefit calculations. Consequently, studies following this approach tend to focus on researchers’ motivations for moving across borders or engaging in collaboration with colleagues from third countries. At the micro-level, the literature shows that the reasons behind scientists’ decisions to engage in international scientific collaboration are manifold. For instance, researchers may decide to participate in international collaborative research to jointly bear the costs of expensive equipment (Licha 1996; Irvine 1998) or because they perceive that the benefits to collaborating with peers from more developed countries are comparatively greater (Narin, Stevens, and Whitlow 1991; Melin and Persson 1996; Glänzel 2001; De Filippo, Casado, and Gómez 2009). Scientists might also engage in cross-border collaboration out of a desire to gain visibility and recognition among peers (Pravdić and Olujić-Vuković 1986; Lawani 1986) or because it increases the chances to access sophisticated research funds (Katz 1994; Dasgupta and David 1994). Likewise, a great deal of empirical work has been devoted to study incentives for mobility ranging from recognition and intellectual autonomy (Stephan and Levin 1992; Roach and Sauermann 2010) to working environments and access to equipment, facilities or expertise (Franzoni, Scellato, and Stephan 2012). Because of this, researchers’ reasons to move are not always easy to determine or predict, especially since the findings of mobility studies are sometimes contradictory (for a review of such studies see Gureyev et al. 2020).

Network: internationalisation as an interconnected network

A network approach to scientific internationalisation involves seeing the international research system as an interconnected communication system through which information is transmitted at various levels (i.e. researchers, institutions, countries and regions). Consequently, the focus of the network approach lies on the flow of information, the communities that such connections form and the power dynamics present at both micro and macro levels. The emergence of the network approach has benefited from advancements in network theory and improved computational capacities in recent years, but especially from methodological developments in Social Network Analysis (SNA). In studying social dynamics of science, SNA proposes an empirical study of scholarly networks, which are uniquely grounded in literature (White 2014, 271). With regards to internationalisation, various studies have examined the
international composition of co-authorship networks (Olmeda-Gómez, Perianes-Rodriguez, and Ovalle-Perandones 2008; Chinchilla-Rodríguez et al. 2012; Alcaide, Zurián, and Benavent 2012). Moreover, Wagner and Leydesdorff (2005) have found that co-authorship patterns are shaped by issues related to visibility, reputation, complementarity and access to resources, rather than factors referring to historical/colonial ties or core-periphery attachment.

An informed reader in STS would note the absence of Actor Network Theory (ANT) in this category. While it is tempting to include it, in essence ANT is not concerned with social connectivity and less so with the international dimension of networks. Indeed, as stressed by Anderson and Adams (2008), ANT (initially) did not deal with geography as it was meant to provide an explanation of ‘immutable mobiles’ (e.g. scientific facts or practices, and technological configurations), arguing that a series of transformations and translations across networks involving human and not human entities, could keep ‘technoscience’ invariant in different settings (Callon 1984; Latour 1987). Although later ANT studies described the reconfiguration of technoscience as it travels across space (see the section in this chapter titled “The diffusion debate”), in general ANT falls better within a constructivist approach.

**Constructivist: internationalisation as a social construct**

The constructivist approach includes a wide family of theoretical schools including the aforementioned ANT as well as postcolonialist, decolonialist and feminist theory. From a constructivist perspective, the international research system is a social construct and internationalisation modes (i.e. collaboration and mobility) are practices subject to constant negotiations and struggles. As noted by Rodriguez (2019, 3), the constructivist perspective has recently proposed a critical reflection on the phenomenon of internationalisation that is based on new sensibilities to power and asymmetrical relations (e.g. Anderson and Adams 2008; Harding 2016). However, what Rodriguez considers as ‘recent critical approaches towards internationalisation’ have more to do with the study of how scientific knowledge travels across geographies, becomes transformed and interacts with other knowledge and practices, rather than engaging with the concept of internationalisation directly. Nevertheless, it could be argued that the constructivist perspective indirectly adopts a conceptualisation of internationalisation as a process (as opposed to an outcome) making the study of how knowledge travels across the spaces of scientific practices a key focus of the constructivist research agenda. In this sense, Anderson and Adams
argue that postcolonial analyses constitute a flexible and contingent framework for understanding contact zones of all sorts, for tracking unequal and messy translations and transactions that take place between different cultures and social positions, as well as between different laboratories and disciplines, even within Western Europe and North America. It is in the transactions of these contact zones that the transformative capacity of internationalisation dynamics came into play.

**Methods for studying scientific internationalisation**

Studies of scientific internationalisation are either quantitative studies based largely on scientometric and bibliometric methods or detailed qualitative case studies exploring the driving factors behind international collaboration, mobility and the impact of multilateral policy initiatives designed to stimulate internationalisation in science. Recently, a limited number of studies have used a mixed-method approach to study dynamics of scientific internationalisation though.

From a quantitative perspective, internationalisation is not regarded as a transformation process but as a “quality that objects or matters can possess to varying degrees” (Gornitzka, Gulbrandsen, and Trondal 2003, 18). It follows that internationalisation can be subject to measurement through scientometric techniques or survey methods. Quantitative studies of internationalisation aim to describe the international dimension of research systems, institutions and networks by looking at empirically observable outputs such as international recruitment rates, the share of internationally co-authored papers, the level internationalisation of R&D expenditure, technological balance of payments, etc. (Godin and Lane 2014). For their part, quantitative studies of international mobility in science have drawn on various types and sources of data, including targeted surveys, general surveys and censuses, repositories of curricula vitae or a combination thereof (Appelt et al. 2015, 180).

While providing a systematic assessment of patterns of scientific internationalisation, quantitative analyses leave unexplored the reasons behind the increase of scientific collaboration and its precise character (Vermeulen, Parker, and Penders 2013) as well as the factors inducing scientific international mobility (Appelt et al. 2015; Baruffaldi and Landoni 2016). Qualitative studies have attempted to fill this gap by exploring the motivations of scientists to engage in internationalist behaviour, considering sociocultural contexts and analysing the functioning and impact of organisations and policies (see Mahroum 1998; 1999; 2005; Ackers 2005;
Another very important focus of qualitative research is the study of transnational organisations devoted to the promotion of scientific internationalisation and the use of indicators designed to monitor the efficient allocation of national resources. Among these, the large empirical work conducted by Benoît Godin within the Project for the History and Sociology of Science, Technology and Innovation (STI) Statistics on the role of the OECD stands out (Godin 2002; 2008). In the case of the EU, the works of Edler et al. (2003) Ackers (2008) and Granieri and Renda (2012) have extensively covered the rationale and impact of regional instruments such as the Framework Programmes (FP) and the EU Research Area.

Lastly, mixed-method studies have recently become more frequent in STS. In the study of scientific mobility, research conducted by De Filippo et al (2009), Jonkers and Cruz-Castro (2013) and Amashita and Yoshinaga (2014) are clear examples. These studies make use of both quantitative and qualitative approaches to investigate driving factors of international mobility. Data sources in these studies vary from interviews and questionnaires to data mining from bibliometric databases. The combination of these techniques allowed these researchers to verify and supplement the results obtained by one method with the results based on other techniques, although it should be noted that the capacity of replication of their results is limited (Gureyev et al. 2020, 1615). For its part, in studies of scientific collaboration, some scholars have sought to address the relationship between the character and structure of organisations and the internal dynamics of science (see Corley, Boardman, and Bozeman 2006; Youtie, Libaers, and Bozeman 2006). In network studies too, Wagner and Fukuyama have used a mix of quantitative and qualitative data to “describe global networks and identify the rules that fuel their operation and growth” (Wagner and Fukuyama 2008, 2). Overall, mixed-method studies seek to establish links between micro and macro levels of analysis in order to fill explanatory gaps of the driving forces behind internationalisation.

**Internationalisation as a conceptual model of transformation in science**

Previously I described some of the intellectual parallels that exist between discussions on scientific internationalisation in HES and STS. I have shown that despite the
emergence of critical perspectives, the dominant discourse of internationalisation prevails in both disciplines. Such discourse advocates an uncritical conceptualisation of internationalisation, heavily rooted in U.S. and Western European contexts and geared towards an outcome-based approach. However, internationalisation is a transformation process marked by tensions that become visible when the phenomenon is regarded beyond the evaluation lenses of the Global North. In this final section, I discuss how internationalisation can be regarded as a model of transformation in the same manner that existing models of change in STS have a dual function for explaining change. Following Vermeulen (2009, 32–33), I argue that the fundamental dichotomy expressed in these models is transferable to the phenomenon of scientific internationalisation. Considering internationalisation as a conceptual model of change has the potential of providing new insights in key theoretical discussions involving dynamics of knowledge production, diffusion and evaluation in science.

Various conceptual models exist in STS that share a fundamental characteristic: they seek to explain how change comes about in science. The Mode 2 concept developed by Gibbons et al. (1994), for instance, describes how contemporary systems of knowledge production are increasingly characterised by greater interdisciplinarity, heterogeneity and social accountability. Mode 2 systems, in this regard, constitute a transformation from Mode 1 systems where knowledge is traditionally produced within disciplinary boundaries, is more homogenous and is usually the product of an elitist enterprise not concerned with social accountability. Likewise, the Triple Helix model developed by Etzkowitz and Leydesdorff (Etzkowitz and Leydesdorff 1998; 2000, 19) aims to explain how in knowledge-based societies a greater entanglement between the spheres of university, industry and government drive innovation. However, unlike the National System of Innovation approach (Lundvall 1992; R. Nelson 1993), in this model is not the firm that plays a leading role in innovation, but the university. Besides Mode 2 and the Triple Helix, the concept of post-normal science (Funtowicz and Ravetz 1994) also denotes a transformation understood in terms of increasing risks and uncertainties when compared with applied science (“normal” science in Kuhnian terms) and professional consultancy.

Similarly, as noted by Vermeulen (2009, 12), the concept of Big Science can be used as analytical tool to explain another transformation in science, in this case, related to the increase of scale. By performing a conceptual analysis, Vermeulen
opened the black box of Big Science and noted how throughout history the concept has taken different meanings. Moreover, like the previously mentioned models of transformation, this concept has a dual function; together with its antonym little science, they form a dichotomy that is used for diagnosing and discussing transformation in science (Ibid, 19). While the normative dimension of transformation models such as Mode 2, post-normal science or Big Science has been criticised (see Weingart 1997, 592), the conceptual duality highlighted by Vermeulen is especially relevant because it points to the possibility that change is science is driven by both positive and negative dynamics.

The changing meanings, the emergence of a dominant discourse as well as counter perspectives, are indicative of the challenge of grasping the nature of complex phenomena such as scientific internationalisation. However, in this case, the duality of the concept of internationalisation expresses in the form of tensions, of which the following stand out:

- **Spatial tensions:** as explained earlier, the relationship between the international and national dimensions of science is symbiotic: to exist, internationalisation requires the national dimension, thus echoing the geographical paradox of science described by Livingstone (2003). Yet at the same time, internationalisation – understood as the process of integrating the international dimension in scientific systems and practices – meets substantial resistance from the national level. On the one hand, the national level, despite the incidence of globalisation, remains a major level of decision, strongly intervening in non-physical flows of knowledge and scientific communication (Zitt and Bassecoulard 2004, 410). On the other hand, while information diffuses cheaply and almost instantaneously throughout the world, the production of scientific knowledge is not equally distributed but is rather concentrated spatially (Gibbons 1994; Olechnicka, Ploszaj, and Celińska-Janowicz 2018).

- **Research ethos tensions:** the second tension is closely connected to the spatial tension and refers to the research ethos that drives scientific internationalisation. The increasing costs of research and the concentration of scientific expertise have led to the emergence of a new international division of scientific labour. In this context, both cooperative and competitive practices
exist, and in some cases new interface relations emerge where competition can be said to be founded upon collaboration (Gibbons 1994, chap. V). However, in the dominant discourse of scientific internationalisation, internationalisation is synonymous with collaboration and transnational solidarity as opposed to globalisation, which is equated to competition. It follows that internationalisation is associated with a research ethos that favours collaboration over competition based on a need for complementarity, of sharing costs, workloads or resources (Gornitzka, Gulbrandsen, and Trondal 2003).

- **Evaluative tensions**: in the dominant discourse, scientific internationalisation is regarded as a highly positive phenomenon that boosts quality and excellence, reduces costs and it increases synergies and efficiencies. This vision feeds the rationales of policies and strategies of internationalisation where policymakers hope to achieve efficiency in higher education systems, import of relevant knowledge, guarantee quality assurance and promote improvements in knowledge production and dissemination (Gornitzka, Gulbrandsen, and Trondal 2003, 132). However, there is also increasing concern over the negative effects of internationalisation, which include pressure in peripheral areas to work and publish in English, or losing intellectual and financial autonomy as a result of participating in international collaborative alliances (Gibbons 1994; Vessuri 1994b; Kreimer 2006; 2015; Rodriguez Medina and Vessuri 2018). A key example of this type of tension involves scientific mobility, particularly the ‘brain drain-gain’ and the ‘brain circulation’ debate. The former (Rhode 1991; RS 2011), involves a large body of literature that focuses on the size and direction of migratory flows to identify clear ‘winners’ and ‘losers’ (Ackers 2005). The latter is built under the assumption that geographical mobility is a reciprocal process without winners and losers, and considers that knowledge diffusion can take place without the physical presence of individual migrants (J. Meyer 2001; Barré et al. 2003; Ackers 2005). Ultimately, each approach perceives mobility differently. Whereas the brain drain-gain approach sees mobility as a unilateral phenomenon affecting mostly developing countries or regions (Fernández-Zubieta, Geuna, and Lawson 2015), the brain circulation approach perceives mobility as multidirectional affecting developed as well as
developing countries or regions (J.-B. Meyer 2003). In sum, tensions are also present in the perceived consequences brought by scientific internationalisation.

- Epistemological tensions: the last tension involves the methods used to study scientific internationalisation, which differ in their assumptions, levels and units of analysis. As I described in the previous section, quantitative methods regard internationalisation not as a transformation process, but as an outcome that can be measured. In contrast, qualitative approaches tend to focus on the motivations and drivers of scientific internationalisation, inquiring about sociocultural contexts and adopting critical perspectives upon dynamics of scientific internationalisation. In general, this tension echoes a greater confrontation between quantitative and qualitative epistemologies in STS (see Wyatt et al. 2015). An in-depth description of this epistemological tension and its implication for the study of scientific internationalisation is provided in Chapter 4, which presents the methodology of the thesis. For now, my goal is to argue that an empirical division marks the study of scientific internationalisation and that research on this phenomenon has a lot to gain from a greater collaboration between these two epistemologies.

As noted by Gornitzka and colleagues (2003, 133), tensions of scientific internationalisation are important puzzles in the internationalisation of higher education and research that should guide future empirical research. An approach to internationalisation based on the acknowledgement of its inherent tensions is therefore adequate to study its complex dynamics. In light of this, in what follows I discuss three key theoretical themes in STS where the conceptualisation of scientific internationalisation as a complex transformation process could provide new insights. In STS, or at least in the following three areas of research, scientific internationalisation demands attention in its own right.

**Theoretical discussions**

While not being a direct topic of research in STS, scientific internationalisation and its tensions are nevertheless present, to a greater or lesser degree, in key theoretical discussions in this field. Namely, (1) the formation of scientific communities, (2) knowledge diffusion processes, and (3) the pursue of research excellence. What these themes have in common with each other and with the concept of scientific
internationalisation per se, is a concern with explaining how change comes about in science.

**Community formation and research ethos**

The concept of internationalisation is at the background of discussions about the formation of scientific communities and their research ethos. The dominant discourse of scientific internationalisation, where internationalisation is viewed as an inherently positive phenomenon, can be found in various discussions such as: (1) the cosmopolitan idealisation of the early scientific communities, (2) the collaborative nature characterising invisible colleges in the era of Big Science and (3) in the description of 21st century invisible colleges as self-organising international networks.

In the age of Enlightenment, the ideal of the ‘Republic of Letters’ was one of the most important expressions of scientific universalism that explained how and why the first communities of scholars formed. As Somsen (2008) notes, “[t]he pursuit of knowledge, according to this ideal, brought people of various creeds and countries together, and inspired a loyalty that stood above religion, family or nation” (p. 363). The irruption of the French Revolution brought a major change in the cosmopolitanism expressed in this ideal as nationalist values began to be associated with the pursuit of knowledge. However, the growth of scientific nationalism did not supplant the supranational qualities of science. In turn, Somsen explains, the cosmopolitan Republic of Letters, understood as community of individuals, transformed into the ‘international scientific community’, meaning an association of nations. In this context, the emergence of scientific communities was not explained solely by the pursuit of universal (or international) knowledge, but also by conscious efforts to set up an organisational structure (e.g. international conferences, unions and associations).

Fast forward to second half of the 20th century, critical transformations in the organisation of scientific practice called for new concepts to make sense of the growth of the scientific community worldwide as well as in the scale and magnitude of the scientific endeavour. In the 1960s, Derek de Solla Price (1963) revived the concept of the ‘invisible college’, initially used to describe the small 17th century British Royal Society who met face-to-face to exchange ideas and research (Welsh and Wright 2010). For Price, invisible colleges and collaborative work were a key consequence of the transition from Little Science to Big Science. What Price originally observed is that the growth of the scientific community in the post-war period was less explained by traditional forms of communication like conferences, unions or summer schools,
but more by the motivation of scientists of *working together*. In other words, larger communities were driven by a stronger collaborative *ethos*. Building on Price’s work, a few years later Diana Crane (1972) argued the invisible college, which according to her resembles a *social circle*, is crucial for the development of scientific communities and provides a sense of membership to a complex national and even global network (Hagstrom 1973; Welsh and Wright 2010).

Parallel to Price’s work in the 1960s, Gorge Basalla made a fundamental contribution to the study of community formation from the perspective of the history of science, which until then regarded inquiries on the spread of scientific communities as secondary matters (Anderson 2018). In his seminal paper, *The Spread of Western Science* (1967), Basalla identified three overlapping phases – non-scientific society, colonial science and independent scientific society – that together provided a linear model for how science diffused from Western Europe to elsewhere. As noted by Anderson and Adams (2008), the diffusionist hypothesis pioneered by Basalla in that paper did not intend to explain the fabrication of scientific knowledge but focused instead in providing a framework for studying the creation of scientific communities and the spreading of scientists over the globe. A description of Basalla’s model and its connection with the notion of internationalisation is discussed in more detail in the next section. For now, it is sufficient to say that Basalla’s model affirms that scientific communities form in an evolutionary manner, passing through different developmental stages that determine the degrees of inclusion into modern science. In this sense, Basalla argued that colonial scientists could not be part of the invisible college “*in which the latest ideas and news of the advancing frontiers of science are exchanged*” (Basalla 1967, 614).

With the emergence of globalisation and the growing interest in internationalisation, these concepts underwent further transformations and along with it, spatial, ontological and organisational structures became the subject of more inquiry. First, inspired by Basalla’s diffusionist model, in the 1990s Schott described the structure of the global scientific community in terms of centre and peripheries. Seeking to explain how the scientific world-system forms, Schott argued that membership in the world scientific community entails a widespread awareness of the most important discoveries wherever they are made. It follows that the centre’s authority is derived from a widespread consensus about its accomplishments and that scientists from nearby locations seek personal contacts with scientists at the centre.
thus forming a periphery tied to the centre (Schott 1991, 448). For Schott, therefore, in a spatially stratified international community, accumulated recognition and legitimacy act as major gravitational forces of the scientific collaborative ethos.

Secondly, the work of Knorr-Cetina contributed to the inquiry into structures by developing a critical perspective against explanations based on scientific universalism. Her comparative work on high-energy physics (HEP) and molecular biology (Knorr-Cetina 1999) showed for instance that invisible colleges differ in their machineries of knowledge construction (i.e. different configurations of the reality), the ontology of instruments employed and their social machineries. In particular, her analysis on social machineries showed that invisible colleges have different communitarian structures that determine their scientific ethos. While HEP presents a more horizontal and collective structure, molecular biology has a more traditional, hierarchical and individualised structure.

Thirdly, research conducted by Wagner and Fukuyama (2008) helped understanding the transformation that invisible colleges have undergone in the 21st century. According to them, the change of century brought the rise of a new invisible college, where the change from the national to the global level has resulted in the acceleration of the diffusion of scientific knowledge. This new invisible college, they argue, is a self-organising international network where researchers collaborate not to serve national interests, but out of desire to complement knowledge and skills (2008: 2). Their argument, therefore, brings back the cosmopolitan vision of the Republic of Letters as it reinterprets the organisation of science as a set of global networks with a scientific ethos that transcends national loyalties.

Studying the role of internationalisation dynamics and its power dynamics, I argue, can add new insights to discussions about the formation and spread of scientific communities. In doing so, one could explain not only how contemporary international scientific communities and their research objects are constructed, but also problematizing the scientific collaborative ethos that is traditionally considered a major driver of this transformation process.

**The diffusion debate: spatial tensions and collaborative networks**

According to Godin (2014, 18), the emergence of the diffusion question can be traced back to discussions among late 19th century anthropologists around a conceptual controversy on possible conceptual frameworks to explain processes of cultural
change. On one side, some considered civilisation to arise in one culture and then to propagate to other geographical communities (i.e. the diffusion hypothesis). On the other side, civilisation was considered the product of parallel and independent developments in every society (i.e. the invention hypothesis). As the controversy placed invention and diffusion in opposition, Godin explains that the solution to this controversy was to consider them as stages or steps of a linear process of cultural change: invention would happen first and then diffuse elsewhere.

In the 1960s the works of two researchers sparked a renewed interest in the diffusion question: sociologist Everett Rogers and science historian George Basalla. The type of influence both scholars had in diffusion studies differ in their nature. On the one hand, Rogers’ work not only contributed to synthetize a vast amount of research on diffusion, but more importantly it set the ground for the sociological study of diffusion from a quantitative perspective. On the other hand, Basalla’s 1967 seminal paper – according to Anderson (2018, A) the sort of “flawed essay that makes us think differently or more deeply” – generated strong reactions by scholars who questioned the linear characterisation of diffusion and helped acknowledging the importance of spatial dynamics in the study of diffusion. While both works have had a crucial role in diffusion research, in this section I will concentrate on Basalla’s diffusionist model and its connection with issues of internationalisation, namely spatial tensions and the role of collaborative networks as vehicles of diffusion. Nevertheless, in Chapter 6, I review Roger’s work in more detail and I discuss its influence on contemporary network diffusion studies.

Influenced by Cold War modernization theory, Basalla conceived modern science as a Western European product and, through the means of a model, he sought to describe how scientific knowledge made its way from Europe to the rest of the world. Although the concept of internationalisation is not explicitly addressed in Basalla’s paper, in his model there are some significant references to its tensions. While Basalla’s emphasis on the unproblematic international nature of scientific inquiry is clearly visible in the first phase of his model, it becomes gradually diluted in the following two. In non-scientific societies (phase 1), science is an extension of geographical exploration characterised by Europeans “visiting the new lands” (Basalla 1967, 611). In colonial science (phase 2), however, more complex patterns of internationalisation start to appear. For Basalla, colonial science is synonymous with ‘dependent science’; not necessarily implying the existence of scientific imperialism,
but rather that formal training, scientific instruments and institutional attachments are beyond the boundaries of the land in which colonial scientists carry their scientific work (Ibid: 613-614). It is in the third and last phase—*independent scientific society*—, where the spatial tensions of internationalisation become more visible. For Basalla the last phase constitutes a *struggle* to establish an independent scientific tradition whereby nationalism displaces internationalism as a driving force of the organisation of scientific practice. In a warning tone, he describes how in the transition from phase 2 to 3, difficulties could arise in the form of scientists’ reluctance to jeopardise their international reputation by publishing in local scientific journals, resistance to create journals in the local language or the absence of a proper domestic technological base (Ibid: 618).

Basalla’s diffusion model became prominent in a time when internationalisation was starting to gain attention and the first concerns were emerging over the gains and losses resulting from the mobility flows of highly skilled workforce across the world (RS 2011). The locality question (e.g. how location matters in knowledge diffusion), the linear character of his model and the power dynamics of space, however, constituted the subjects of critiques for many years by scholars interested in the social study of science.

In general, the fiercest response against the diffusionist model came from postcolonial scholars who emphasised the relevance of locality and called for the replacement of linear models with notions of ‘mutual interdependence’ and ‘contact zones’ (Anderson and Adams 2008). Such concepts stress the importance of looking at the social interactions taking place between contextually different actors and the knowledge transformations that emerge due to these exchanges (see Shapin 1998; Anderson 2009). In this sense, the postcolonial response meant not only a defence of the locality question, but also a recognition of the reciprocal character of the circulation of ideas. Nevertheless, the power dynamics of these exchanges are often left unexplored in postcolonial analyses and, as noted by Chambers (1987), the lack of a general framework in the postcolonial response increases the risks for researchers to sink into a ‘sea of local stories’ (p.314).

With the acceleration of globalisation in the 1990s and the growth of collaborative science, Basalla’s diffusionist model added more critics but also gained adepts. For Thomas Schott (1991), the diffusionist model regained momentum as it helped to explain knowledge diffusion processes in terms of centre-periphery
dynamics in a more interconnected scientific community. Diffusionist studies have also drawn on network theory to study the hierarchical power structures in global scientific collaboration networks and the uneven diffusion of knowledge and expertise across geographies from a quantitative perspective (see Wagner and Leydesdorff 2005; Leydesdorff and Wagner 2008; Glänzel, Schubert, and Czerwon 1999). More recently, these new network studies have started to acknowledge the spatial tensions that exists in the global scientific collaborative network. In diffusion research, this has led to a debate between models emphasising the importance of local buzz – i.e. direct interactions within local settings – and those stressing the importance of global pipelines – i.e. communication with contacts located outside the local milieu – for fostering innovative development (Storper and Venables 2004; Bathelt, Malmberg, and Maskell 2004; Torre and Rallet 2005; De Noni, Ganzaroli, and Orsi 2017; Olechnicka, Ploszaj, and Celińska-Janowicz 2018, 130).

Overall, since Basalla’s paper came to light, postcolonial and diffusionist research agendas have operated a different scales of analysis. Postcolonial researchers have focused on the locality question with an emphasis on the circular nature of knowledge diffusion while ignoring the global connections and the power tensions of space. For their part, diffusionist research has become more quantitative-based and concerned with describing the structure of the global diffusion network. Only recently, it has started to pay greater attention to the question of space. In light of the difference between these approaches in science history, Livingstone argued:

To be sure, science must take place somewhere; location, like embodiment or temporality, is essential to knowing. The real question is how do particular spaces matter in the production, consumption and circulation of science? In what ways do local and global forces conjoin to shape scientific culture in specific places? (2005, 100).

The challenge mentioned by Livingstone is essentially a reflection of the spatial tensions of scientific internationalisation, which if adopted as a research subject in itself, can add new insights into the diffusion debate. Namely, by considering social networks – a point where both diffusionist and postcolonial studies seem to agree – and by studying their spatial configuration, there is great potential for understanding how spatially distinct collaborative networks intervene in the diffusion of scientific knowledge. Moreover, while studying spatial tensions in collaborative networks is a way to observe power dynamics in knowledge diffusion at a global scale (i.e. do
international networks are more predominant in peripheral communities?), it is equally important to understand the meaning of these networks for actors, and in particular peripheral actors. In doing so, more comprehensive models of scientific development could be developed (Chambers 1987).

**Internationalisation and excellence**

A third major discussion refers to the close relationship between the notions of research excellence and internationalisation. Internationalisation is considered an important means to achieve excellence and at the same time, internationalisation is often used as an indicator of research excellence. With the advent of globalisation, as excellent science was increasingly being perceived as a key asset to compete internationally in the knowledge-based economy (Chesnais 1990; Godin and Lane 2014), the line separating both concepts became even more blurred. Evaluative scientometrics, a term coined by Francis Narin (1976) that refers to the use of quantitative indicators for measuring research performance and impact, has been a key, if not the most important, architect of this (con)fusion of concepts – i.e. the tendency to equate research excellence with indicators of internationalisation such as international mobility, international co-authorships or higher citations in mainstream English language journals. While the concept of excellence in the scientometric approach has been subject to intense criticism, in the scholarly debate the relationship between excellence and internationalisation has been less scrutinised.

In the pre-evaluation era (1970s and 1980s), the concept of research excellence attracted a fair amount of academic interest, mostly from sociologists and psychologists focusing on the origins and characteristics of scientific prestige and stratification processes in science (R. J. W. Tijsen 2003, 91; see also Godin 2008). Throughout this time, various studies set out to identify a series of attributes associated with scientific productivity at either the level of individuals (e.g. sex, age, education), institutions (e.g. size or available infrastructure) or the environment (e.g. labour policies, public and private funds, etc.) (for a review of these studies see Abramo, D’Angelo, and Di Costa 2009). The launching of the Science Citation Index (SCI) by Eugene Garfield in 1964 constituted a milestone in the study of research excellence later on.\(^2\) The SCI provided academics and policy-makers with a

\(^2\) Originally, the SCI was not intended for measuring research excellence. It was created for the prime purpose of retrieving scientific information, and the ideas of a citation index were discussed years before the commercial product was launched.
centralised collection of journals and publications and therefore a unique source of empirical data that shifted the focus from the determinants of scientific productivity towards the measurement of scientific influence and impact, paving the way to the emergence of evaluative scientometrics.

In *Little Science, Big Science* (1963), a benchmark of scientometrics, Derek de Solla Price described how since the 17th century the scientific paper transformed into the main channel through which scientists communicated their findings. Building on this assumption and the possibility to study the social aspects of science through mathematical methods, scientometrics adopted publications as the ‘building block’ of science and as the main source of data (Van Raan 2005). Moreover, the ontological basis of scientometrics rest on the premise that scientific literature is a real and independent object that can be studied from a distance hence avoiding subjectivity or bias (Wouters 1998, 226). Because it focuses on the numbers associated with the performance and outcomes of research, evaluative scientometrics is thus considered a non-reactive tool (i.e. other researchers accessing the same datasets can achieve similar results) and a valuable complement to the value-laden methods of qualitative peer review (Subramanyam 1983; Kostoff 1995, 199). In this sense, the scientometric perspective had a profound impact in the policy discourse on research excellence, which evolved from a conceptualisation of ‘scientific excellence’ rooted in academic virtues and peer review processes towards one of ‘research excellence’ that is grounded in measures of research outputs and their commercial application (Sørensen, Bloch, and Young 2016, 3).

In the widest sense, research excellence is a comparative measure that can be defined as adding value or special significance to research activities (R. J. W. Tijssen 2003). From its beginning, evaluative scientometrics added an international dimension to the definition of value. The pioneering works of Narin (1976) and Martin and Irvin (1983), for instance, argued that the best proxy to assess research performance is international scientific influence as measured through citation-based bibliometric analysis. Citations analyses are based on the central assumption that scientists’ citing behaviour is an indication of the positive value they attribute to the cited work. As international journals are a dominating, or at least a major, means of communication in most of the natural, medical and behavioural sciences, the higher the number of citations a paper receives, the higher the international influence of that paper (see Van Raan 2005).
The literature, nevertheless, identifies at least two problems with this account. On the one hand, citation analysis’ core assumption on colleague recognition is contested because citation behaviour cannot always be equated with positive judgments on the work of others. For Cozzens (1989), for instance, most references have a rhetorical character and this point, she notes, seems to be neglected in most citation analyses. For Hasselberg (2013) too, intentions or habits behind citation are simply not relevant in evaluative scientometrics. Because of this, and the continuous tensions in defining and measuring it, research excellence remains an ‘essentially contested concept’, meaning a widely appraised but at the same time controversial phenomenon (Ferretti et al. 2018, 732).

On the other hand, despite arguments in favour of the objective character of citation analysis, as a unit of measurement, citation is a socially constructed concept, not a natural kind. Therefore, citation is best understood as an ‘institutional fact’ because it relies on a social agreement (contested, nevertheless) at the ontological level over its meaning (Searle 1995). Yet citation analysis is, above all, performative. To illustrate this, Woolgar (1991) refers to citation analysis as a measurement technology, which once applied to the concept of quality results in modifications (or redefinitions) of what counts as quality. Based on this, I further argue that evaluative scientometrics (including citation analysis) contributed to shape the meaning of excellence, quality, visibility, productivity or simply recognition in science in international terms; that is, linking it with citations in mainstream and English language scientific journals. In other words, for evaluative scientometrics, excellence should be understood at the international level.

Recently, in a report titled ‘Promoting Research Excellence: New approaches to Funding’ (2014), the OECD warned that as national scientific systems face an increasingly competitive environment for ideas and talent, the question of public funding allocation becomes even more pressing (p.15). In this context, research excellence initiatives have proliferated across the world, with each country seeking to attract top scientists and foreign talent, to raise the international reputation of domestic research institutions as well as providing large-scale, long-term funding to designated research units (see OECD 2014; Ferretti et al. 2018). Because of the policy pressure to develop metrics to monitor these phenomena, the relationship between research excellence and internationalisation has become even more entangled. For instance, it is common to find dimensions of internationalisation in indicators of research
excellence beyond international citations, like international collaboration, international mobility, world rankings or attraction of foreign investment (see OECD 2014; EC 2014; R. Tijssen and Kraemer-Mbula 2018; Cremonini, Horlings, and Hessels 2018). Similarly, the proliferation of internationalisation strategies since the late 1990s and early 2000s has been driven by the need to enhance recognition and reputation at the supranational level. Particularly, these strategies pursue such goals as achieving or strengthening research excellence (including access to foreign resources and facilities), increase the attractiveness of domestic systems to overseas researchers (e.g. inward mobility), boost the international marketisation of domestic innovations as well as contributing to the solution of global challenges (see Edler and Flanagan 2011; OECD 2005; Reale et al. 2012; Van den Besselaar et al. 2012).

Along with the policy interest in the internationalisation-excellence tandem, scientometrics methods have also been used increasingly to study the social dimensions of this relationship. In particular, contemporary quantitative studies of science have revived the interest in the determinants of research excellence with a focus on the modes of internationalisation. A wide amount of empirical work, for instance, has demonstrated the positive correlation that exists between international mobility – as a measure of internationalisation – and the number of publications and citations – as measures of excellence (Sugimoto et al. 2017; Robinson-Garcia et al. 2018; Halevi, Moed, & Bar-Ilan, 2016; Aksnes, Rørstad, Piro, & Sivertsen, 2013; Halevi, Moed, & Bar-Ilan, 2015; Hunter, Oswald, & Charlton, 2009; Hunter et al., 2009; Jonkers and Cruz-Castro 2013; Edler, 2007; Edler et al., 2011).

Likewise, various studies have shown that internationally co-authored papers tend to have higher citation rates than domestic papers or non-collaborative work (Narin, Stevens, and Whitlow 1991; Glänzel, Schubert, and Czerwon 1999; Persson, Glänzel, and Danell 2004; Didegah and Thelwall 2013). Moreover, some studies have described the core-periphery structure reflected in the relationship between internationalisation and research excellence. By considering the role played by authors in international collaborations, these studies found that core countries seem to benefit most from international collaboration when they lead the research, whereas peripheral countries benefit most from being led (Olechnicka, Ploszaj, and Celińska-Janowicz 2018; see also Guerrero Bote, Olmeda-Gómez, and Moya-Anegon 2013). Overall, scientometric studies have reinforced the relationship between both concepts
by placing them in a linear framework of scientific practice where internationalisation leads to higher research excellence.

While the direct relationship between levels of internationalisation and individual excellence or quality has been criticised from an evaluative perspective (see Ackers 2008), the processes by which internationalisation affects the notion of excellence have not yet been studied. As noted by Tijssen (2003, 94), the notion of research excellence is, on the one hand, shaped by the collective beliefs and goals of research communities and on the other, it may depend on how and where research outcomes are assessed. In this sense, scientific excellence should be studied within the context of specific research communities. Furthermore, when understood as a complex transformation process expanding across various dimensions (e.g. scientific practices, knowledge infrastructures, evaluation systems, etc.), the study of internationalisation can reveal not only how internationalisation practices relate with research excellence, but also how internationalisation dynamics shape and constrain the notion of excellence within and across research communities.

Discussion

In this chapter, I provided an overview of internationalisation with the aim of making sense of this complex phenomenon from a theoretical, methodological and a spatial point of view. I described how the meaning of internationalisation has evolved in the HES since the 1990s. While in recent years, the concept has widened its scope, in HES internationalisation continues to be regarded as a positive and unproblematic phenomenon. This, I noted, results mostly from intellectual and policy paradigms coming from the U.S. and Europe that together form the dominant discourse of internationalisation we see in academia and science policy.

This dominant discourse not only sustains the rationales of internationalisation strategies in higher education but it has also transpired into social studies of science and technology. In STS there has not been a collective scholarly debate about the meaning of scientific internationalisation with the same depth and rigour as in HES. However, internationalisation has been and continues to be a topic of interest in this field. Under the label of the ‘the social study of scientific internationalisation’, I set out to describe the large yet dispersed literature in STS dealing with the international dimension of science. In general, I note how this rich body of literature has only engaged with the study of internationalisation rather indirectly and circumstantially,
focusing mostly on the modes and patterns of internationalisation and less so on the complex transformative dynamics of internationalisation. The complexity of the transformative quality of internationalisation, I argue, is illustrated in the tensions of this phenomenon. Internationalisation is a complex transformative process driven by conceptual, spatial, evaluative and epistemological tensions. In light of this, I developed a case in favour of considering scientific internationalisation as a conceptual model dealing with transformation process to the same level as other renowned conceptual models in STS. Consequently, I finished the chapter discussing how this new conceptualisation of internationalisation can provide new perspectives and insights into key theoretical discussions in STS involving dynamics of knowledge production, diffusion and evaluation in science.

In the next chapter, I continue exploring the meaning of scientific internationalisation. I discuss how scientific internationalisation is not only a complex relational phenomenon driven by tensions, but it is also subject to different contextual interpretations. This ‘contextuality’ has disciplinary and geographical dimensions. In this first case, I discuss the impact of the dominant discourse of internationalisation in social studies of the life sciences and in particular, research on model organism science, whose research ethos draws heavily from this imaginary. In the second case, I examine the meaning of scientific internationalisation from a South American perspective. Scientists and research managers from this part of the world tend to view internationalisation as a complex relational phenomenon that has both positive and negative connotations.
Introduction

On January 27 2017, just a week after he was sworn into office, President Trump issued Executive Order 13769, establishing travel restrictions to the U.S. for citizens coming from seven Muslim-majority countries. The signing of the Executive Order provoked widespread criticism and protests both in the country and abroad. Detractors of the bill stood up to denounce the major impact it would have not only on immigration, industry and human rights, but also on research and education. It was in this spirit that, a few months after its signature, a group of neuroscience labs in Cold Spring Harbor (CSH) decided to respond to the government’s travel ban by releasing a series of contrasting group photographs showing what less-open international borders would do to their workforces (figure 1). The shrinkage from the first image (showing everyone who works in this centre), to the last (showing only those researchers’ whose parents were born in the U.S.) is quite striking. In some cases, about two-thirds of the staff were lost (Nature 2017). In essence, this original initiative was a clear political statement in favour of scientific internationalisation: by making it less internationalised, science shrinks, until it almost disappears.

Figure 1. CSH’s response to Trump’s travel ban. Source: http://zadorlab.labsites.cshl.edu/CSHL_Neuro.gif (Nature 2017)

While the symbolism of this protest speaks about the internationalist character of scientific research in general, the action ultimately constitutes a response by a
group of U.S.-based life scientists. In other words, the meaning of the protest has specific spatial and disciplinary contexts. First, the statement in favour of internationalisation – expressed in the form of international mobility – reflects a spatially bounded vision of internationalisation, namely a U.S. vision. A strong international dimension is a consolidated feature of the U.S. research system: a 2012 survey, for instance, showed that more than 60% of postdocs in the United States were brought up overseas (see Van Noorden 2012). Accordingly, from a U.S. policy perspective, internationalisation is related to brain gain or, in other words, the country’s capacity of attraction of highly skilled scientists (Robinson-Garcia and Ràfols 2020, 218). It follows that internationalisation in the U.S is frequently given a highly positive connotation and is regarded as something that should be promoted or, in this particular case, protected.

Second, the vigorous defence of internationalisation is a common characteristic of the life sciences, which has become a more internationalised, collaborative and networked field over the years thus moving away from the traditional image of an individually centred, non-collaborative and lab-bench science (Vermeulen 2009). Yet at the same time, I argue, a dominant discourse of internationalisation becomes evident with communities often depicted as uniform and harmonious international ecosystems governed by a strong collaborative ethos. This has very much shaped our understanding of practices in many scientific fields, including the life sciences, in as much as we consider internationalisation and science to be mutually constitutive.

Scientific internationalisation is a complex transformative phenomenon subject to different contextual interpretations. In Latin America, in particular, scholarly debates around scientific internationalisation have been linked historically to wider questions about dependency, asymmetries and development in (and beyond) science, which continue until present days. Consequently, visions of internationalisation in this region often portray a mixture of positive and negative connotations, which indicate a more complex conceptualisation of this phenomenon that is often observed elsewhere (see Kreimer 2006; Vessuri 2016).

In this chapter, I continue exploring the meaning of scientific internationalisation. In Chapter 2, I presented a general overview of the phenomenon of internationalisation and of scientific internationalisation in particular. I described how, despite recent developments in its conceptualisation, scientific
internationalisation continues to be perceived primarily as a positive and unproblematic phenomenon and not as a transformation process involving complex power dynamics. This attitude, I observed, results mostly from intellectual and policy developments coming from the Global North that have formulated the dominant discourse of scientific internationalisation.

I will now examine the significance of internationalisation from the perspective of South American life sciences. Research on life has a long record of development and a strong strategic importance for South American countries. Preceded by physics, the life sciences has become the second scientific field with the highest production rate in the region (measured in published papers) and it is also the second with the highest percentage of international collaborations (measured in international co-authorships) (RICYT 2020). Although it is a field where internationalisation dynamics have had a strong presence historically, the peripheral contexts in which life scientists develop their research in South America suggest a contrast with existing accounts of internationalisation dynamics in the life sciences at the global scale, which have not been fully examined.

Investigating the contrast between scholarly descriptions of the life sciences and discussions on scientific internationalisation in South America is the main goal of this chapter, which is structured in three parts. Taken together, the three sections aim to present the reader with a ‘conceptual expedition’ through which dominant discourses of internationalisation in the life sciences are examined next to past and contemporary visions of internationalisation in South America.

In the first part, I look into the mainstream STS literature on the life sciences and I examine how dynamics of scientific internationalisation are portrayed in this field of research, with a special focus on studies of model organisms. As part of the conclusions of this introductory analysis, I argue that these studies tend to decontextualize the research communities they study, focussing on their international projection while ignoring the power dynamics present in them. In other words, this body of literature leaves unattended notions of asymmetry and dependency present in scientific practices and in the structural configurations shaping the norms and expectations operating in life sciences’ international communities.

In the second part of the chapter, I discuss notions of scientific internationalisation in Latin American life sciences. I first conduct a historical review of discussions on scientific internationalisation in Latin America, with a special focus
on studies related to the life sciences (Cueto 1989; Kreimer and Lugones 2002). Efforts to make sense of internationalisation dynamics show that scientific internationalisation is a major topic of interest among Latin American authors albeit approached from a distinct conceptual perspective. By focusing on questions of dependency, asymmetry and development, academic discussions in this region have tended to describe scientific internationalisation as a dilemma: ‘to internationalise or perish’. Yet, unlike the well-known ‘publish or perish’ aphorism, ‘perishing’ here denotes not only a pressure to publish and obtain international recognition, but also a risk of losing scientific autonomy, understood in cognitive, material and socio-political terms.

I then examine contemporary visions of scientific internationalisation in South American life sciences, collected via interviews I conducted with scientists and research managers in three South American countries (Argentina, Chile and Uruguay). Reflections on this exploratory analysis lead me to develop a contextualised definition of scientific internationalisation of South American life sciences: a transformative and relational process driven by tensions in practices of resource exchange, knowledge diffusion and research excellence. These complex dynamics are the subject of the empirical analysis on this thesis, which takes zebrafish – a relatively novel model organism whose growth in Latin America has been unprecedented – as a case study of transformative processes in the life sciences produced by internationalisation.

The internationalisation of the life sciences

In many respects, the historical process of specialisation in modern science have rendered multidisciplinary collaboration necessary for the advancement of research as no single researcher is able to make theoretical or applied contributions in more than one narrow area of research (Hara et al. 2003). Collaboration, across geographical and disciplinary boundaries, therefore, has become a distinctive feature of contemporary science that increasingly deals with broader and more complex problems, demands highly specialised talent, requires expensive instrumentation and largely depends on multilateral funding (Hoekman, Frenken, and Tijssen 2010). Moreover, high levels of physical (i.e. geographical) mobility have long been the standard in academia, especially in the natural sciences further reinforcing the relationship between excellency and internationalisation from an evaluative perspective (Ackers 2008). Well-known examples of these trends are the so-called
Big Science disciplines such as astronomy or high-energy physics where the physical disposition of instruments prompt mobility and long-distance collaborations.

Recently similar dynamics have been observed in the life sciences as well. According to a recent report by the National Science Foundation (NFS), the biological sciences are the third scientific field with the highest share of international co-authorships behind astronomy and the geosciences (NSF 2018). Research on life therefore not only has become bigger, but also more internationalised.

Research on life has not always been considered a big, collaborative and internationalised field. The comparative analysis conducted by Knorr-Cetina in Epistemic Cultures (1999) for instance showed that as opposed to the more horizontal-collaborative research ethos of big physics, collaboration is less common in molecular biology. Moreover, when cooperative behaviour occurs in molecular biology, Knorr-Cetina argues it does so driven by a “logic of exchange” involving services and potential co-publications (Ibid: 255). In other words, collaboration in the life sciences is a strategic behaviour driven by individual, circumstantial and practical motivations, rather than by epistemic factors.

However, some scholars have recently shown that both transdisciplinary, transnational and large-scale cooperation are not exclusive features of big physics. As noted by Vermeulen (2009; Vermeulen, Parker, and Penders 2013, 254), the history of biology shows a shift from single-investigator (i.e. 'little science') to a 'Big Science' that is increasingly large, collaborative, international and networked scientific discipline. In order to characterise big biology, she compares developments in biology to traditional big physics and shows how big biology differs from big physics as a form of big science. She first explores the history of collaboration in biology, demonstrating that next to big physics, biology has a long history of collaboration as well (e.g. the alliance between science and exploration during the 17th century or the interdisciplinary collaborative First Polar Year in the late 19th century) (Vermeulen 2009, 42–43). Vermeulen further argues that, whereas practices of collaboration are not new to the life sciences, recent technology developments in biology have caused organisational transformations in terms of growth and the movement towards collaboration. Examples include large-scale international research programs like the renowned Human Genome Project (HEP) or the Census of Marine Life, and multilateral research organisations such as the aforementioned CERN or the European Molecular Biology Organization (EMBO). Yet unlike in big physics, in the
life sciences such organisational transformations are ‘centrifugal’ and have a more ‘networked’ character (Vermeulen 2009; Vermeulen, Parker, and Penders 2013).

Other studies have examined differences in internationalisation according to different (sub)disciplines (Parker, Vermeulen, and Penders 2010). In ecology and environmental studies, Zimmerman and Nardi (2010) compared the Long-Term Ecological Research Network (LTERN) with the National Ecological Observatory Network (NEON) and noticed how competition between them configures different approaches for making ecology a big science. For its part, Parker (2010) studied the integration of the social sciences into ecological collaborations and the challenges for recruitment and cooperation faced by scientists from three different organisations working to advance a recent scientific/intellectual social movement. In systems biology, Calvert (2010) examined interdisciplinary and disciplinary identities, reflecting on some of the communication problems that arise in this highly collaborative field.

**Internationalisation of model organisms**

In addition to the above studies, a great amount of STS research has focused on genomic and model organism research. Model organisms are non-human species that are comprehensively studied in order to understand a range of biological phenomena, with the aim that the knowledge generated as a result, could be applicable to other organisms, particularly those that are more complex than the original (Leonelli and Ankeny 2013). Model organisms’ communities, with their attention for material and information exchange, became the predecessors and a role model for the HGP, next to big physics. Well-known documented cases are the global collaborations around model organisms such as *Drosophila* and as *C. Elegans*. In the case of *Drosophila*, a long history of collaborative networks where researchers shared “mutants and know-how” (R. E. E. Kohler 1994, 134) paved the way for the standardisation of this model early on, accomplishing large-scale genetic mapping in the 1970s (Nüsslein-Volhard and Wieschaus 1980) and the mapping of its full genome sequence by the beginning of the 21st century (M. D. Adams et al. 2000). For its part, the introduction of *C. elegans* into the way of work of sequencing had a profound impact in the international dimension of this mapping project. As noted by García-Sancho (2007), the already existing international community of worm researchers grew and increasingly begun exchanging – in this case – mapping and sequencing data (p.137).
Throughout the 1990s and early 2000s, international collaborative networks became a key feature of the various genomic sequencing projects that took off in the context of the HGP. In this sense, model organisms' communities and the infrastructures that support them constitute key examples of the organisational transformations induced by internationalisation dynamics in the life sciences. As noted by Ankeny and Leonelli (2011), with advent of the HGP, granting bodies started recognising the value of model organism research by funding not only genome sequencing projects but also 'community resources' such as stock centres and cyberinfrastructures (see also Leonelli and Ankeny 2012). In the era of the Internet, online community databases and platforms are said to have displaced traditional communication means such as newsletters and meetings and have contributed significantly to strengthen communication and collaboration in these communities as well as dramatically increasing the quantity of information on model organisms and the number of researchers with access to such information. Moreover, community databases are creating new standards and guidelines for what counts as reliable evidence, intelligible nomenclature and acceptable experimental practice. This has rendered databases into critical mechanisms for division of labour and the fostering of collective trust within and between model organism communities (Ibid).

In general, practices of collaboration and resource exchange (e.g. techniques, specimens and data) are said to be common to all model organism communities, which have themselves become models for good behaviour in science (see Rosenthal and Ashburner 2002; Ankeny and Leonelli 2011; N. C. Nelson 2013). As such, the pillars of these research communities are formed by practices commonly associated with the positive effects of internationalisation, including: more international and increasingly accessible community infrastructures, transnational collaborative networks and a social commitment to openness expressed in actively contributing to develop such community resources. This scientific “repertoire” is crucial for to the point it explains how relatively stable communities of researchers in the life sciences are created, managed and persist in the long term (see Leonelli and Ankeny 2015).

The previous descriptions reflect, to a large extent, the impact of the dominant discourse of scientific internationalisation in the social study of the life sciences. I argue that while these studies describe – albeit indirectly – the transformative impact of internationalisation dynamics in the life sciences, they tend to decontextualize the very same international research communities they analyse and ignore the power
dynamics present in them. In particular, they leave unexamined notions of asymmetry and dependency in practices of resource exchange as well as the structural configurations that determine the norms and expectations operating in these communities. What remains then is a propensity to view such communities as uniform and harmonious international ecosystems governed by a strong and inherent collaborative ethos.

The above statement does not assume that lack of critical studies examining the complexities of internationalisation dynamics in the life sciences (see Manning and Savelli 2018). Recent research has focused on the connections between localities and global processes in various (sub)disciplines. Wright, Mullally and Saucier (2018), for instance, revisited well-established notions of brain drain and brain gain, exposing the complexity of scientific migration flows in medicine. Their study on the migration of Indian physicians to the U.K. and the U.S. shows how brain drain phenomena are best understood as co-operation processes that combine deteriorating conditions in the countries of origin and the adoption of absorptive policy mechanisms in receiving countries. Similarly, Worlfe (2018) reveals the tensions between internationalism and nationalism in the spread of American biology textbooks. In the 1960s, biology textbooks constituted a tool to advance American hegemony, yet at the same time, they also expressed national ambitions of postcolonial societies in Asia and Latin America.

Overall, though the emphasis established by these studies on the multi-directionality of historical interactions in the life sciences is insightful, they also tend to blur asymmetries between the different meanings of key dichotomies like ‘internal-external’ or ‘basic-applied’ between centres and peripheries. In many peripheral countries, these dichotomies have continued shaping local research, which is often assessed for its social relevance and its connection with national development needs. This has revived debates not only around basic-applied dichotomies but also about autonomy–dependency, Latin American STS being a key example of this (Liscovsky Barrera 2019b).
Latin American studies of internationalisation

Scholars tend to divide the evolution of Latin American STS into two large historical phases\(^3\). In each of these periods, notions of scientific internationalisation can be identified, all of which share a concern with questions of dependency, asymmetry and development.

A first phase (1950s-1970s) comprises the beginnings of STS in the region when a mixed group of thinkers and technologists denounced the lack of a national orientation in programmes sponsored by international organisations aiming to foster scientific development in Latin American countries. Accordingly, I argue that by standing in clear opposition to these internationalist policy initiatives, this group of STS pioneers exploited the tension between the international and national dimensions of science from a socio-political perspective, which set the ground for contemporary studies on scientific internationalisation.

A second phase (1980s-present) witnesses the institutionalisation and subsequent consolidation of STS in Latin America. In this period, a larger share of sociological and anthropological micro type of analyses begun to emerge, increasingly more interested with theoretical rather than practical aspects as in the previous phase. Contemporary STS Latin American scholars tend to portray internationalisation as a dilemma: ‘to internationalise or perish’, where the latter denotes a risk of losing intellectual and material autonomy vis-à-vis the U.S. and Europe.

1950s-1970s: science, technology, development and dependency

The first discussions on scientific internationalisation can be traced back to the beginnings of STS in Latin America in the 1960s and 1970s. Throughout this period, various technologists and thinkers reacted against the ideas of the so-called ‘science (supply) push movement’ (‘movimiento ofertista’ in Spanish), predominant in policy-making circles during the 1950s and early 1960s.

\(^3\) All of the reviews I consulted on the history of STS talk about a Latin American STS tradition thus suggesting a wider spatial, economic, socio-political and scientific framework than the object of this thesis, South America. While the majority of the authors discussed here are South American, the reader is reminded that terms such as ‘Latin America’ and ‘South America’ as well as its variants, are meant to be interchangeable (see Introduction).
The policy consensus that emerged in the context of U.S. post-WWII efforts for re-industrialisation stressed that technological innovation and economic progress critically depended upon scientific progress. This vision was summarised in Vannevar Bush’s renewed report to the U.S. President, titled *Science, the Endless Frontier* (1945). In the periphery, the specialisation of countries during the postwar period led to a dependency of capital, resources and technology from central countries, and with it structural and chronic underdevelopment. Accordingly, in Latin America, the Economic Commission for Latin America and the Caribbean (ECLAC) and the Organisation of American States (OAS) sponsored a series of international programs based on this consensus that were destined to promote industrialisation policies as a means to overcome underdevelopment (Galante and Lugones 2005).

The ideas of the ‘movimiento ofertista’ were mostly based on the ideas of ECLAC’s first Secretary General, Raúl Prébisch. In his seminal paper titled *The Economic Development of Latin America and its Principal Problems* (1950) – described by Hirschman as sort of ‘Latin American Manifest’ equivalent to Rostow’s ‘Non-Communist Manifesto’ (UN-ECLAC 2008, 9), Prebisch drew attention to the issues affecting the underdevelopment of Latin American countries and its causes. Namely, deteriorating terms of trade between centre and periphery that perpetuated a relationship of dependency. The conclusions of the report translated into organised efforts in Latin America during the 1950s and 1960s to promote industrialisation, increase public investment in science and technology and support the establishment of national scientific councils, thus echoing the policy initiatives implemented in the U.S. and Europe at the time.

By discussing Latin American issues from a specific spatial perspective, rather than just placing them within a universal development ladder, paradoxically Prebisch’s work set the stage for the critical perspective adopted by various authors in the following years (Sábato and Botana 1968; Varsavsky 1969; Herrera 1972). According to Arellano and Kreimer (2011a), the dependency thesis introduced by Prébisch acted as a common ground for the works of the first STS authors in the region, who criticised the process of technology transfer as a ‘dependency phenomenon’.

Sharing a common concern with questions of development and dependency related to science and technology, the writings of this heterogeneous group of authors marked the beginning of STS in Latin America. Accordingly, some scholars have described this pioneering group of thinkers under the label of *The Latin American
School of Thought in Science and Technology for Development (LASTSTD, aka ‘the School’) (see Martínez Vidal and Marí 2002; Arellano Hernández and Kreimer 2011a; Thomas 2010). Nonetheless, the LASTSTD was not an ‘academic’ school strictly speaking; that is, it did not form around an existing theoretical corpus nor was it based on the ideas and teachings of a group of thinkers that together produced novel conceptual and methodological frameworks locally. Instead, the ideas of LASTSTD were strongly linked to discussions around S&T policies at the time, which meant that agenda-setting, rather than theoretical development was the main concern of this group of authors (Arellano Hernández and Kreimer 2011a).

The LASTSTD criticised the ‘movimiento ofertista’ of the 1950s-1960s in the sense that, while it supported the creation of infrastructures, programmes or institutions that generated a supply of scientific knowledge locally, such supply, they argued, did not respond to a specific demand, even less so a ‘Latin American demand’. Consequently, the authors of the LASTSTD stood to claim, along with industrialisation, the ‘endogenization’ of technology – i.e. the creation of a local capacity to absorb the imported technology, adapt it to local requirements, and produce new technology locally (Martínez Vidal and Marí 2002, 5). In sum, the general critique by the LASTSTD to the ‘movimiento ofertista’ stressed that the ideas of this movement acted as a policy instrument that – ironically – reproduced the dependency they sought to overcome. The critique entailed, at the same time, a defence of alternative analytical instruments, such as the concept of ‘national project’ (i.e. a political programme that takes into account local interests and priorities over foreign intervention) and the ‘social demand of science and technology’ (i.e. the social utility of scientific knowledge and innovation produced in the region) (Thomas 2010; see also Alonso and Naidorf 2019).

One of the predominant voices within the LASTSTD, geologist Amílcar Herrera, denounced the contradictions between policy goals and the national demand. Noticing the almost absolute failure of international initiatives to foster S&T, Herrera (1972) argued that the scientific underdevelopment of Latin American countries was not due to an absence that could be solved through external assistance, but rather a necessary consequence of their economic and social structure. As such, the development programmes sponsored by UNESCO and the OAS failed to

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4 Thomas (2010) described this group of pioneers under a similar but slight different label: The Latin American Thought on Science, Technology and Society (LATSTS).
recognise the difference between what he called ‘explicit’ and ‘implicit’ science policies. The former is the ‘official policy’; the one expressed is the laws, regulations and programmes developed by the state bodies in charge of planning science, in the public discourse, etc. The latter is the one that practically determines the role of science in society, though it is more difficult to identify because it lacks a formal structure. In essence, implicit science policies express the S&T demand of the national project in each country (Ibid p.27). Herrera concluded that a key character of underdevelopment is the contradictions between these two set of policies. From the perspective of scientific internationalisation, Herrera’s work can be re-interpreted in the following manner: the internationalisation of S&T policies and their materialisation as the explicit science policy of Latin American countries was unavoidably at odds with their own national demands and development goals.

Note that Herrera (as many of the authors of the LASTSTD) did not discuss the social aspects of scientific practice, but was rather concerned with the normative and political aspects of scientific development. Similarly, the work by physicist Jorge Sábato addressed the development challenges faced by Latin American countries in science and technology. His ‘Triangular Model’ (1968) proposed in collaboration with Natalio Botana – and precursor of the renowned ‘Triple Helix’ model (Etzkowitz and Leydesdorff 1998) –, described a successful dynamic of development sustained by the virtuous interaction between the state-industry-science axis. The model gained widespread acceptance within Latin American countries and helped diffuse the assumption that the state ought to play a critical role in fostering an endogenous transfer of technology (Arellano Hernández and Kreimer 2011a).

Notions of scientific internationalisation are perhaps more explicit in the work of Oscar Varsavsky; one of the most radicalised voices of the LASTSTD. In the writings of this mathematician, one can find vigorous attacks to the internationalist vocation of scientists and the structural determinants of modern science that, according to him, perpetuated a relationship of dependency of Latin American scientists with the central countries. Varsavsky criticised what he called the ‘scientism’ (‘cientificismo’ in Spanish) of the Latin American scientist who, in his view:

“...has adapted to the scientific market, refuses to worry about the social significance of his activity, dissociating it from the political problems and focusing entirely on his ‘career’ while accepting the norms and values of the major international centres” (Varsavsky 1969, 59–60).
Varsavsky further noted that by travelling to the Northern hemisphere and accepting unconditionally its leadership, Latin American scientists carried a ‘cognitive burden’ that was sustained through the international linkages they maintained upon their return – either directly or indirectly via funding institutions or scientific societies. These international connections, he added, formed an ‘international scientific bureaucracy’ that diffused news and norms from central countries to the rest of the world. In this sense, unlike his colleagues Herrera and Sábato, Varsavsky explored the social dimension of science beyond its politics and was one of the first voices in the region to question the basis of the universal character of scientific knowledge:

“...the universality of science is due much more to [such] organised diffusion than to the convergence of scientists. Scientists from all countries are already united in an aristocratic international, which apart from other defects is a danger to the evolution of humanity” (Ibid 91).

This ‘scientism’, he further warned, was an important factor in the ‘de-nationalization’ process of Latin American scientific systems, which reinforced their cultural and economic dependency and turned them into satellites of certain world development poles. The Latin American scientist, he concluded, is ‘underdeveloped’ because despite using the most modern techniques, his labour is reduced to supply raw materials (i.e. empirical data) to be analysed at international centres (Ibid: 61).

Overall, in the different works that make up the LASTSTD, we can identify early notions of scientific internationalisation connected to questions of development and dependency. I argue that, by standing in clear opposition to the international programs sponsored by UNESCO and the OAS, the ideas of the ‘School’ established an early antagonism between the international and national dimensions of science. Moreover, by criticising the lack of a national perspective on development in the diffusion of scientific policies, norms and values, this conceptual tension paved the way for the problematisation of the concept of scientific internationalisation later on.

1980s - Present: ‘internationalise or perish’

From the 1980s onwards, Latin American STS began a process of consolidation in which sociological and anthropological research based on case studies gained predominance over the normative analyses of the previous decades. Most notably in the last ten or fifteen years, the Latin American STS literature came to fill a gap in the social study of internationalisation and developed a critical perspective that was
missing in internationalisation studies (see Chapter 2). Sometimes breaking with the classical diffusionist model while in others embracing it fully, this new critical perspective continued to focus on the development question and developed detailed case studies to show how internationalisation both enables and hinders scientific research in the periphery. In general, I argue, this new critical approach towards internationalisation can be summarised in the following maxim: ‘to internationalise or perish’. However, unlike the well-known ‘publish or perish’ aphorism, the meaning of ‘perishing’ denotes a dilemma between the pressure to publish and obtain international recognition, and the threat of losing scientific autonomy. In a context that some scholars describe as dominated by the normative power of globalisation and neoliberalism (Martínez Vidal and Marí 2002), such definition represents a problematisation of the concept of scientific internationalisation that contrasts with the assumptions of the dominant discourse of internationalisation.

Back in the early 1980s, the works of Díaz, Texera, and Vessuri (1983) as well as Cueto (1989) introduced the concepts of ‘peripheral science’ and ‘excellency in the periphery’ respectively to analyse how world-class research can developed far from the centres of knowledge production and circulation. Cueto (1989) described the success of high-altitude physiology in Peru since the 1930s thanks to the ability of Peruvian researchers to capitalise on their natural environment, to attract the financial backing of American foundations, and to implant themselves in international networks of scientific communication. Cueto’s analysis therefore breaks with the classical diffusionist thesis to argue that internationally recognised modern scientific knowledge can develop in peripheral contexts when local researchers are able to exploit available niches (Click 1991). Research conducted by Díaz, Texera, and Vessuri and colleagues (1983; for a good review see also Vessuri 2016) on the other hand showed that the articulation of local knowledge with ‘mainstream’ international science (i.e. European or U.S.) took different shapes depending on historical and ideological contexts. In some cases, such production entailed a ‘direct dependency’ that at times could resemble a mimetic isomorphism, whereas in others, scientific production showed degrees of ‘relative autonomy’ and was more geared towards local dynamics and problems. In the 1990s, Vessuri concluded that a key feature of peripheral science is the disjunctive ‘international’ versus ‘national’ and its impact on the notion of ‘utility’ (i.e. the local relevance of research), which according to her, does not affect North American or European researchers in the same manner as scientists in developing countries (see Vessuri 1993; 1994b; 1994a).
Vessuri has also explored with more detail the notion of *asymmetry*. Her recent study on the cooperative behaviour among Mexican social scientists, co-authored with Rodríguez Medina (2018), showed that international cooperation involves not only an uneven distribution of resources (i.e. static perspective), but also an equal capability of processing and disseminating scientific knowledge (i.e. dynamic perspective). These asymmetries, Vessuri and Rodriguez Medina conclude, explain why Latin American scientists tend to acquire a strategic and mercantilist vision of their careers through which internationalisation becomes a means towards greater capitalisation thereby risking loosing creativity and autonomy (Ibid, p.31).

The above conclusion is derived from earlier studies conducted by Vessuri and colleagues (Vessuri, Guédon, and Cetto 2013) on the normative power of bibliometric databases. There she describes these international databases as global mechanisms that reproduce biased notions of internationalisation and which are blind to development issues (Ibid p.653). Vessuri further claims that by transforming quality into a ranking measure, these databases have introduced competition as the management tool of the global research system and, at the same time, they have defined the rules of such competition based almost exclusively on North American and European evaluation practices. The implementation of evaluation policies based on citation measures, she continues, tends to work against development as it leads to the adoption of the ‘international’ research agenda while indefinitely postponing scientific attention to local problems (Ibid). This constitutes a reinforcement of the ‘dependentist’ thesis by which internationalisation is synonyms with the notion of ‘research excellence’ and placed in opposition to the concept of ‘local usability’ of scientific knowledge.

Other researchers like Lea Velho and Pablo Kreimer relied on and further expanded the notions of periphery and utility. Velho’s (1996) work on the Maracá Rain Forest Project, involving the Royal Geographical Society of the UK and the Amazônia National Research Institute (INPA) of Brazil, demonstrated how networks of international cooperation in peripheral biological sciences are largely determined by the power imbalances between core and periphery. Gama and Velho’s (2005, 206) studies have shown the lack of representation of Latin American scientific journals and the existence of language biases in international citation databases as well as the strong patterns of international collaboration that exist between Latin American countries and extra-regional countries (see Fernández Muñoz, Gómez Caridad, and Sebastián 1998; Gómez, Teresa Fernández, and Sebastián 1999; Lewison, Fawcett-Jones, and Kessler 2005; Sancho et al. 2006; Russell et al. 2007; De Filippo, Barrere, and Gómez 2010).
analysis of INPA’s policy of international collaboration, greatly favouring foreign scientists in terms of access to the Amazonian natural resources, further illustrated that in North-South collaborations, developed countries usually define the project/program and become the sole owner of the results.

Pablo Kreimer is perhaps the STS scholar who has contributed the most to develop the study of scientific internationalisation in Latin America, with a special focus on the life sciences. Kreimer updated the dependentist thesis of the 1970s and further explored the relationship between the notions of ‘periphery’ and ‘internationalisation’ pointed out by Vessuri in the 1980s and 1990s. Kreimer’s work examines scientific internationalisation from a socio-historical perspective and argues that the autonomy of Latin American science has gradually reduced over the years. For Kreimer, internationalisation has been present in the region since the late 19th century when the personal relationships that local scientists forged with research leaders in Europe favoured the development and institutionalisation of the first modern scientific fields. This initial phase, which he labelled ‘Founder Internationalisation’, was followed by a second phase that he describes as ‘the long phase of Liberal Internationalisation’ and which modified the nature of the relationships between scientists. The second phase was characterised by the ‘subordinated integration’ of Latin American science to the research themes and resources of the central countries (Kreimer 2006; 2013). By ‘subordinated integration’, Kreimer means a dilemma that resulted from the links local research groups maintained with international research partners. On the one hand, because the training of the majority of leading Latin American scientists took place in institutions of central countries with whom they collaborated, the latter often retained a ‘cognitive control’ (and most of the time also an economic control) of the research. Yet at the same time, collaborations with these prestigious institutions was a necessity for Latin American research groups as they provided a basis for greater local legitimacy in terms of the quality and international visibility of their research (Kreimer 2013, 443; Kreimer and Zukerfeld 2014).

Kreimers’ work on the history of molecular biology in Argentina (Kreimer and Lugones 2002; Kreimer 2011) is particularly illustrative of these dynamics. Kreimer described the key transformation process the discipline underwent as a result of its subordinated integration to mainstream international molecular biology. Foreign postdoctoral trainings and the conservation of international cooperation networks
established upon their return, assured the adoption of research lines developed in laboratories from the U.S and Europe and gave Argentinean molecular biology an ‘imitative’ character.

Nowadays, according to Kreimer, the integration of Latin American scientists into the international research community has deteriorated. The international division of research labour, greater developments in information and communication technologies and the expansion of international research in the form of mega research networks, have further restricted the boundaries of negotiation for peripheral research groups as well as reinforced a ‘false notion of autonomy’ (Kreimer 2006; 2013; Kreimer and Meyer 2008). These three developments show that nowadays the biggest tensions refer to the limited relevance and potential local application of research produced by strongly internationalised research groups. In light of this, Kreimer and others went on to argue that contemporary dynamics in internationalisation leave little space for attending to local problems (Kreimer 2006; Bonfiglioli, and Marí 2005; Kreimer and Thomas 2003; Kreimer and Levin 2011; Kreimer 2006).

Kreimer’s work therefore brings together in an unorthodox manner the concepts of internationalisation, periphery, excellence and utility characteristics of Latin American STS. At times, his work stands close to Basalla’s' diffusionist thesis showing how knowledge and resources are mobilised from the centre to the periphery. His work on the Chagas disease however (as discussed in more detail in the next chapter), also follows a similar approach to that of Cueto’s in the sense that it breaks with diffusionist based explanations to explain how South American countries – namely Argentina and Brazil – were able to developed front-line research in a relative autonomous way (Kreimer and Zabala 2006; 2007).

Some reflections about Latin American studies of scientific internationalisation

In contrast to the dominant discourse of internationalisation adopted by the mainstream STS literature, which regards internationalisation mostly as a positive process and a desired outcome (see Chapter 2), contemporary Latin American STS scholars have contributed to problematise the concept of scientific internationalisation. Addressing notions of development, asymmetries and dependency, the works of these authors are based on detailed anthropological case
studies of internationalisation practices that provide empirical evidence for the antagonisms introduced by the LASTSTD in the 1970s: international vs national; periphery vs centrality; autonomy vs dependency and so on.

This problematisation should not be reduced to highlighting the negative aspects of internationalisation dynamics. Instead, problematizing internationalisation involves recognising alternative paths for scientific development. As noted by Fernanda Beigel (2016), the existence of multiple circuits of knowledge (e.g. alternative international bibliometric databases, regional data repositories and networks as well as local/national circuits of non-indexed journals) compartmentalises – and therefore problematizes – Latin American scientific production beyond the mainstream-marginal binary. In light of this, she warns that Latin American STS need to go beyond the simplistic stereotype of comparing intellectual autonomy with ‘centrality’ and heteronomy with ‘periphery’ and should analyse dependencies and asymmetries as "concrete situations", its background being the relational approach of Latin American historical-structural tradition (Ibid, p.9).

Nevertheless – and to conclude this review –, Latin American studies of internationalisation, and particularly research conducted on the life sciences, have mostly been based on historical and contextualised cases that illustrate how scientific knowledge has been produced autonomously despite working from the periphery and with inadequate conditions (see Cueto 1989; Velho 1996; Kreimer and Lugones 2002; Kreimer and Zabala 2006; Kreimer 2011). There is, therefore, a need for updated studies on scientific internationalisation in order to explain how knowledge is produced from the periphery in a context marked by a greater incidence of international collaboration and mobility in science. In other words, we still have little understanding of how internationalisation dynamics intervene in contemporary Latin American life sciences.

**Internationalisation dynamics in contemporary South American life sciences**

In the last section of this chapter, I unpack specific elements of scientific internationalisation in South American life sciences. The analysis of interviews across different disciplines in three different South American countries (Argentina, Chile and Uruguay) is meant to serve as a contrast to the dominant visions of internationalisation in the life sciences described above. At the same time, I am to assess the extent to
which the problematisation of scientific internationalisation in Latin American STS literature is present in contemporary practices of knowledge diffusion, resource exchange and notions of research excellence in this field of research.

**Dynamics of internationalisation in practices of resource exchange**

Along with the strategic approach towards internationalisation, a key aspect emerging from the interviews with South American life scientists concerns notions of asymmetry in terms of access to resources. For instance, discussing experiences of international collaboration, the majority of researchers argue that these often allowed them to circumvent the challenges of conducting research, which has become increasingly expensive, time consuming and technologically-driven. This strategic attitude, they claim, is further reinforced by their immediate local contexts: e.g. distance from main centres of knowledge production, constant budget restrictions and volatile national science policies. As noted by one Argentinean researcher working on cellular and molecular biology in a private university located in Buenos Aires:

> Practically nothing is manufactured here and we need those inputs to make agile science and be able to compete. Note that in the U.S., you ask for a reagent from SIGMA and you have it in 24 hours. Here they pass you the budget after a while and until you do the paperwork and the product arrives, it can take up to three months. And you pay triple the cost of the US; between three and five times more. (PI-Argentina-1 2018)⁶.

The above quote shows how notions of asymmetry often become visible for South American researchers. Geographical distance from supply centres and restrictions to the import of vital research resources constitutes a key factor shaping the meaning of internationalisation in South American life sciences. From this perspective, the ‘international’ scientific community operates as a market where the lack of a scientific critical mass translates into fewer incentives for supply companies to operate in the periphery. It follows that key resources for peripheral scientists are frequently located outside the local milieu, hence increasing both the costs and time devoted to conduct research. All of this reinforces a sense of inequality that is attached to the idea of scientific internationalisation itself.

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⁶ All the interviews with South American scientists were conducted in Spanish. The English translation is my own.
For many researchers, notions of asymmetry in terms of access to resources first became evident under experiences of international mobility. Almost all the researchers I have interviewed in this project have done placements abroad for short and long periods of time. They stressed how these experiences not only shaped their careers but also made them appreciate what is like working in other contexts and under different conditions. A researcher from a leading international research institute based in Montevideo explains in comparative terms what is like conducting research in Uruguay based on his/her experience working abroad:

Even though the world is so global today, you still feel far away – physically far away – when you need something. So, you have to plan your experiments differently. I remember when I was in the U.S. that if you were doing an experiment and you ran out of something, you bought it, you came back and you kept doing the experiment. Or you called the company and said ‘hey, for tomorrow I need this antibody’ and the next day you had it. Here it takes months. And it’s not just that: you pay $100 for the antibody and $500 for shipping. So not only do we have much less money for projects, but we also spend four times what Americans spend on the same product; without considering the enormous discounts that universities get there. There is not a single university that pays the list price. You call and say you are from Hopkins and SIGMA already lowered you 30%. […] So the truth is that here [you end up] juggling to work.(PI-Uruguay-1 2018).

In Argentina, a head of laboratory working with pigs and sheep on cardiovascular research describes a similar situation; in this case, based on the experiences of his/her postdocs when they travel to the U.S. or Europe:

These kids right here [points to the room next to us]... they have all done placements abroad. They came back dazzled because they were able to work and they tell you stuff like: “you know they have like a sort of supermarket within the university. You go with your little basket, you pick the antibody you want and you go to the register where they ask your grant number. They scan it and… peep, peep [imitating the scanner sound]. Like a supermarket!” So they return to their laboratories to start the experiment like half an hour after they had designed it. Here it takes four months...if you have the money. (PI-Argentina-2 2018).

These last two testimonies are examples of how practices of international mobility bring visibility to asymmetries in science. This contrasts with descriptions of internationalisation made by researchers during the interviews when I asked them to
define internationalisation. There they often used words such as *universal, democratic* or *equal*. However, when talking about their experiences of international mobility and collaboration, notions of asymmetry emerge. These two cases show that while science means ‘speaking the same language everywhere’ (PI-Uruguay-3 2018) – as one researcher put it –, international mobility, a key practice of internationalisation, in contrast highlights the difference of conducting research between distinct places of scientific practice; between centre and the periphery. A difference that South American researchers count in *kilometres* and *months*.

Yet at the same time, internationalisation is a means for South American life scientists to circumvent structural asymmetries. Experiences of international mobility allow researchers to build networks that could become highly valuable upon their return to their home countries. These networks of international collaborators help them to reduce financial and time costs when it comes to access research resources. In recent years, internationalisation practices, and collaboration networks in particular, have become more institutionalised, to the extent that some research institutions from the U.S. and European countries have established branches in South America; well-known examples include the Max Planck Institute in Buenos Aires or the Institute Pasteur in Montevideo. However, the majority of international collaborations are not the result of institutional arrangements between laboratories but are still a product of the relational capital of South American researchers and their career trajectories.

The connections researchers establish with other scientists while working and studying abroad translate into key assets to access resources that are not immediately available back home including specimens and samples but also antibodies or reagents. Because of the administrative and customs barriers to export these materials, in the majority of cases their exchange is done through researchers themselves who travel abroad and bring it with them. Head of laboratories send their PhD students and postdoc researchers to institutions where they themselves studied and worked, or to other institutions where they have colleagues with whom they worked in the past. In this sense, the joint publication between two laboratories becomes not only the currency of this exchange but the instrument that *formalises* internationalisation practices.

Collaborations for accessing resources are not always preceded by experiences of international mobility. In some cases, uncertainties and lack of resources are key incentives to actively search for partners abroad. However, in these cases too,
asymmetries between collaborating partners become visible either because of the greater dependency of one partner on the resources of the other to conduct research or the power differentials that exist between the two partners. One Argentinean scientist, working with mice on immunology and microbiology, for instance, explains how the changing national context has rendered international collaborations a necessity to conduct research:

I think that those of us that nowadays are doing well is because we seized the opportunity ten years ago when things were flourishing and we became stronger in that moment. Collaborations came later. I mean, to continue at this level, I needed a few resources I did not have and so I started to look for partners abroad. [...] It is a matter of structure. Though we are growing in numbers, we do not have the capacity [in this lab] to create knockout mice with certain genes [...] There were times when, if it was not for these collaborations, we could not have done certain stuff. (PI-Argentina-3 2018)

Moreover, when collaborations do involve an actual exchange of resources between partners, power differentials between the two set the limits to the terms in which these exchanges unfold. In the following example, because of the nature of the biological material – i.e. human tissues –, the exchange unavoidably had to be done through official channels:

Nowadays, exchanging resources is a very complicated issue. In our case, we work with human biological materials and barriers to this exchange are critical. Yet these barriers do not actually exist when you participate in a [international] clinical trial. This is very problematic for the country because when a multinational conducts a clinical trial it takes back with it all the biological material quite easily. If you want to do the same, you will need to register with the Health Ministry and that takes months. In my case, I am still waiting for a reply. So, exchanging materials is very complicated (PI-Argentina-4 2018).

These examples are illustrative of the extent to which dynamics of internationalisation in practices of resource exchange are complex. That is, while they reflect dependencies and asymmetries in themselves, practices of internationalisation also constitute key means to bypass structural asymmetries – e.g. detrimental local conditions or the existence of restrictions to access biological and other day-to-day working materials. In the latter case, however, the notion of internationalisation is still closer to dynamics of dependency rather than complementarity, which is a notion commonly found in the dominant discourse of internationalisation. As such, from the
perspective of South American life sciences, internationalisation is largely placed in opposition to the notion of autonomy. Yet in this case, autonomy is understood almost exclusively in material terms thus portraying a different dynamic of internationalisation than described in the context of Latin American STS literature where emphasis was also placed on the cognitive dimension (e.g. imposition of research lines by foreign partners). As will be shown next, this difference is largely explained by transformations taking place in recent years in the life sciences at the global scale that seem to have increased the material dependency of local research groups with the centres of knowledge production.

**Dynamics of internationalisation in knowledge production**

From the point of view of South American life science researchers, dynamics of knowledge production taking place in international collaborative networks are less related to epistemic or cognitive dimensions of research but have more to do with access to equipment and technology. As explained by one Argentine researcher working on humoral immunology:

> Generally we seek collaborations with countries with greater scientific development (not intellectual but technological) since they allow us to achieve results that in Argentine laboratories we have more difficulty. [These] collaborations do not usually give you the money, but they have funds that if you can travel there, they provide you with the technology and reactive tools whose costs we cannot afford here (PI-Argentina-5 2018).

Another Chilean researcher and academic manager describes similar motives for engaging in collaborative partnerships:

> In international collaboration [...] we mainly seek to capture technology. We are keen to establish collaborations on local or regional problems using technological platforms that only exist in developed countries and which are practically impossible to develop here in the next 10 years. For instance, proteomics, genomics, big data, and so on [...] Therefore, in my opinion, there is an oversupply in developed countries. They have platforms but they do not have projects of such depth that they can fully exploit that capacity. [In turn] we have projects but not platforms, so generating [these] links is important for us (RM-Chile-1 2018).

According to these views, international collaboration for knowledge production in South American life sciences is mostly driven by access to technological resources.
This is certainly a key aspect of the Latin American perspective of internationalisation in the life sciences. Across the interviews, I did not find indications that the motor of these partnerships was access to novel ideas nor that international partners impose research lines or questions in exchange for these resources. Interviewees in turn described the increasing dependency on these networks from a technological point of view, where the joint publication nevertheless constitutes the currency of the exchange. This contrasts with existing research work in Latin American STS that discusses the negative aspects of international collaboration networks from a dependency point of view covering not only technological and financial dimensions, but also a cognitive one (Varsavsky 1969; Alatas 2003; 2014; Kreimer 2006; Beigel 2016; Rodriguez Medina and Vessuri 2018).

In general, the increasing dependency on international networks relates to the transformation of the life sciences into a technologically-driven discipline. This means that dependency dynamics of internationalisation captured in the life sciences are particular of historic and disciplinary contexts. In this wider transformation process, access to sophisticated and expensive research infrastructures – and less so novel ideas, research agendas or questions – act as key drivers of transnational scientific collaboration among South American life scientists. One Uruguayan describes this context based on his/her trajectory:

I always thought that if you were trained in good universities (in the first world), and if you had a little bit of luck and money, you could come back and continue doing, more or less, the same research. The problem is that this was true until the first half of the 90’s. Later on, technological developments made science became much more ‘machine-dependent’. Very large quantitative advances changed the way of doing science because machines began to be able to do things that you could not be done before: all the stuff related to the biological analysis of information; the most sophisticated equipment for screenings and images, the regeneration of knockout mice, and so on. I mean, there were many things that made science require a lot more infrastructure, and which was impossible to bring here because of the millionaire investments it demanded. In the second half of the 90s and early 2000s, that gap became enormous, almost unfathomable (PI-Uruguay-2 2018).

In addition to this, subsidies by local granting bodies allocated to the purchase of equipment are often limited. In the worst cases, once approved, funds are
converted to the local currency at a fixed price for the duration of the research project, which means that inflation limits even further the laboratories’ purchasing capacity:

The biggest barrier is the lack of resources, which is reflected – you probably heard it already – in the grants [...] In terms of equipment this is a terrible thing because most of the time you have a pool of money assigned to the purchase of equipment that [eventually] is worth 40% less; the devaluation means you cannot afford this equipment. (PI-Argentina-4 2018).

Internationalisation practices thus provide access to technologies and infrastructure that have increasingly become vital for conducting research on life. Moreover, because international partners often provide access to technology and infrastructures, here too joint publications become the currency of these exchanges. Yet as with practices of resource exchange, most interviewees confirmed that the definition of the research questions and the experiments designed in these international collaborations are generally not subjugated to the interests and demands of international partners, but are rather the result of preceding and independent lines of research (PI-Uruguay-3 2018; PI-Chile-1 2018; PI-Argentina-3 2018; PI-Argentina-6 2018).

**Dynamics of internationalisation in notions of research excellence**

From the point of view of researchers, practices of internationalisation are not only a strategic tool for building their relational capital, but also a key aspect of their training as scientists. On the one hand, experiences of international mobility and collaboration help South American life scientists acquiring a first-hand understanding of the notion ‘research excellence’, meaning working under or with privileged research contexts. Almost all of the researchers I interviewed for this project stressed that geographical mobility is mostly motivated by the benefits of experiencing what is like to work under ‘different conditions’, which include higher funds, better equipment and higher performance in less time. These advantaged conditions, in their view, are also key explanatory factors of the higher chances for research groups in developed countries to publish in mainstream international journals, which are the main proxy by which research excellence is measured. For instance, one Argentine researcher working on immunology talks about the importance of international connections for their research:

> It seems to me that it is a quite an important factor, first from a technical point of view. We collaborate with people who give us things that we do not have, and that is key to answering questions that allow our work to
have a higher quality and greater impact and therefore be published in better journals (PI-Argentina-3 2018).

In particular, practices of international collaborations and mobility are thought to increase the quality of the research as well as their chances of publishing in international and high-ranking scientific journals. Because of the technological transformations of the life sciences described earlier, researchers stress that novel research ideas are often not enough to be able to publish in high-indexed journals. As explained by a Uruguayan researcher:

There are very few cases in which you can do all the work in Latin America and get into those journals. This is for several reasons. One of the main ones is that the level and amount of work that these papers require is very large considering the budgets we have. The kinds of techniques they use are also expensive. Therefore, the budget you have is negligible for what you want to do. [...] A project that in Europe is 250 thousand euros, in Uruguay it is 30 thousand dollars [...] So your work capacity is tremendously limited. But, even if we had all the money, we would lack the contacts [...] It also happens that it depends on the names listed in the publication. So having external collaborators who have a good level and a good reputation means that your work can enter some places that otherwise it would not be possible. (PI-Uruguay-3 2018)

This trend has been confirmed at a larger scale. In a recent survey conducted by the Ibero-American Network for Science and Technology Indicators (RICYT) to researchers from Argentina, Brazil, Chile, Colombia and Mexico, around 75% of the more than 6,800 respondents considered collaboration with international partners as a facilitator for publishing in international scientific journals (REDES 2017). This relates to the linear framework of internationalisation and research excellence of evaluative scientometrics discussed in Chapter 2, whereby internationalisation is thought to lead to higher research excellence.

On the other hand, science evaluation practices in South America for some time have included the notion of ‘pertinence’ (i.e. alignment of research with national development priorities) to assess quality research in calls for grants. In theory, both the notion of local pertinence as well as the international recognition of research groups (validated through their publication records in mainstream international journals) frame the notion of research excellence when it comes to allocate financial resources. As explained by an Argentine top civil servant working in the National
Evaluation Agency – the country’s main body for assessing research projects – evaluation practices tend to involve a mixture of national and international dimensions:

[On the one had] we have the notion of pertinence; that is, the idea that scientific research has to have some sort of articulation or anchorage with national production goals. But at the same time, we copied - in fact, we had people visiting us from the National Science Foundation - indicators related with the idea of science as excellence. So we have a mixture (PM-Argentina-1 2018).

A similar approach is found in Chile and Uruguay (interviews with RM-Chile-1 2018; PM-Uruguay-1 2018). On the one hand, the idea of pertinence coexists with imported standards of research excellence. In practice however, in local evaluation practices, international standards dominate the conceptualisation of research excellence. For instance, when research projects involve an international partnership, the existence of a previous record of collaboration between the two institutions (e.g. joint publications) is taken into account along with the access to research infrastructure that should be guaranteed by the international partner (PM-Argentina-1 2018). In this sense, evaluators tend to connect the assessments of viability of research projects with the existence of international partners that assure access to sophisticated research infrastructures.

The notion of pertinence is also less prominent in career evaluations, which like project evaluations tend to prioritise publications indexed in mainstream international databases. In the aforementioned survey conducted by the RICYT, 98% of respondents confirmed publications in mainstream journals are a very important aspect in the evaluation of their scientific performance (REDES 2017).

In sum, the relationship between internationalisation and research excellence seems to adjust to the linear description of evaluative scientometrics. These statements confirm the observation made by some Latin American STS scholars (Vessuri, Guédon, and Cetto 2013; Kreimer 2006; 2015; Beigel 2016), that the conceptualisation of research excellence rests almost exclusively on imported parameters: namely, publication in international mainstream scientific journals. However, the analysis also suggests that this relationship of dependency has become more entangled and difficult to overcome as a result of the complex transformations taking place in the life sciences. As science becomes more technology-dependent,
‘quality’ research in South America becomes more critically dependent on internationalisation practices.

**Discussion: a contextualised definition of scientific internationalisation**

The previous analysis shows some contrast and similarities with Latin American STS literature on the one hand, and mainstream STS literature on the life sciences on the other. Highlighting these contrasts took me to develop a contextualised definition of scientific internationalisation that is meant to serve as a starting point from which to address questions on how internationalisation dynamics intervene in contemporary practices of knowledge production and diffusion in South American life sciences.

First, Beigel’s (2014; 2016) critique of the simplistic stereotype of comparing intellectual autonomy with ‘centrality’ and heteronomy with ‘periphery’ characteristic of the STS Latin American tradition seems to be accurate. The analysis of testimonies by South American life scientists confirms that international collaborations with colleagues from developed countries are largely motivated by a need to access sophisticated research infrastructures and technologies. Local research agendas however are not, in the majority of cases, subjugated to the interests and demands of international partners. This indicates that contemporary dependency dynamics are less related to epistemic dimensions, but are rather motivated by access to critical material resources. In this sense, the conceptualisation of internationalisation as a dilemma, as formulated by the Latin American STS literature, should be updated to consider particular historical and disciplinary transformations in science. In the case of the life sciences, its recent transformation into a more technology-dependent research field rendered internationalisation a necessity for accessing sophisticated research infrastructure and technology to conduct research in peripheral settings.

Second, internationalisation is a transformative process of science that is set in motion by the relational capital of researchers. The connections South American life scientists establish when working, studying and travelling abroad are key assets for accessing material resources to conduct research in their local and peripheral contexts. International co-authorships are the currency that formalise these largely informal connections. However, this does not simply translates into a description of the life sciences as a research field driven by a ‘logic of exchange’ (Knorr-Cetina 1999). Instead, as shown from the perspective of South American life scientists,
structural asymmetries trigger exchanges between distant and unequal partners. This means that while at the global scale, the life sciences have become a more collaborative and internationalised field, its research ethos is not a consequence of epistemic transformations crossing geographical borders. Instead, asymmetries in terms of access to critical equipment and technology have turned international collaboration and mobility into crucial practices in contemporary processes of knowledge production and diffusion in the periphery.

Third, notions of research excellence are strongly dependent on internationalisation dynamics. In this respect, the Latin American STS literature has long noted how evaluative practices in the region rely on rules based almost exclusively on North American and European evaluation practices. Accordingly, notions of research excellence are dependent on imported definitions of quality that tend to work against local development goals. However, once again these assessments should take into account historical and disciplinary transformations. Particularly, as the life sciences evolved into a technology-dependent field in recent years and materials capabilities are not being distributed equally across the globe, definitions of quality research in South America have become more critically dependent on internationalisation practices. International mobility and collaboration are key assets enabling South American life scientists to access privileged research infrastructures and materials. This certainly adds a layer of complexity to the linear framework of evaluative scientometrics whereby internationalisation leads to higher research excellence.

These reflections took me to develop a contextualised definition of scientific internationalisation of South American life sciences: a transformative and relational process driven by tensions in practices of resource exchange, knowledge diffusion and research excellence. These complex dynamics are the subject of the empirical analysis in this thesis, which takes the zebrafish – a relatively novel model organism whose growth in South American has been unprecedented – as a case study of transformative processes produced by internationalisation in the life sciences.

The above definition is intended to work as an entry point to address questions left open by this introductory analysis. In the following chapter, I provide more detail about the research questions, approach and methodology guiding this investigation.
Chapter 4: Research Design and Methods

Introduction

This chapter presents the general research design and methods used in this thesis. To study internationalisation dynamics in South American life sciences, I make use of the model organism ‘zebrafish’ as a case study. The growth of this little tropical fish in biologic and biomedical research has been unprecedented in South America, and its relatively novelty makes it a suitable case to study how complex dynamics of scientific internationalisation intervene in processes of knowledge production and diffusion.

Overall, I consider the study of scientific internationalisation as requiring insights from both quantitative and qualitative methods. Accordingly, I make use of bibliometric techniques, social network analysis (SNA), statistics as well as qualitative methods including interviews, ethnographic observations and document analyses. As mixed-methods approaches are rare – although increasingly more frequent – in STS, I discuss the implications, limitations and opportunities of combining methods in this particular discipline.

The empirical chapters that follow this methods chapter address specific transformative dynamics of scientific internationalisation. In each of them, I use a different combination of the above techniques and I provide a detailed description of the methodology used to answer the research questions laid out in those chapters. However, as some of these methods and techniques may not be known to the reader – most notably bibliometrics and SNA –, in this chapter I explain the basic concepts of these approaches with the intention of facilitating the reading further in the thesis.

Case study design: the zebrafish model

Along with a methodology that favours a combination of methods, this research will follow a case study design understood as an ‘all-encompassing method’. That is, a comprehensive research strategy covering the logic of design, data collection and analysis (Yin 2003, 14). In particular, I will use zebrafish – a small tropical fish commonly used as a research model in biological and biomedical research – as a case study to investigate transformative processes produced by internationalisation dynamics in contemporary South American life sciences.
On using models organisms as ‘models’ to study social dynamics in science

Model organisms such as the fruit fly, the worm or mice have become ubiquitous in the life sciences, achieving a ‘translational momentum’ in the sense that human disorders are increasingly linked to animal models and biomarkers (Kalueff, Echevarria, and Stewart 2014). Yet at the same time, models organisms have served as ‘models’ for studying social dynamics of scientific research. Well-known examples in STS are Kohler’s (1994) study of the Drosophilist community, the analysis of the Arabidopsis community conducted by Rhee (2004) and Leonelli (2007; 2008), Ankeny’s (2000; 2001) work on C elegans, and Kelly and Lezaun’s (2017) ethnographic study of mosquito colonies, among others.

In Latin American STS, Kreimer (2016; 2019; Kreimer and Zabala 2006; 2007) used Chagas, a disease caused by a parasite, Trypanosoma cruzi, as a ‘model’ to study social dynamics in scientific research conducted in the periphery at different levels. First, Chagas is a disease that exists solely in Latin America and therefore solutions to treat it cannot be ‘imported’ from elsewhere. In this sense, Chagas allowed Kreimer to study the relative autonomy through which countries in this region have viewed this endemic disease over the years.

Second, Chagas served as an ideal model to study the crossover between science and politics, observing the many ways in which the problem has been constructed as well as the approach designed to resolve it. The case of Chagas could be defined in many terms: as a health, societal, economic, pharmaceutical issue and so on. In this sense, for Kreimer Chagas is performative because in every approach, knowledge, disciplines, actors and institutions are mobilised to produce and describe different realities (Kreimer 2019).

Third, and perhaps more important for this thesis, Kreimer used Chagas as a model to show the tensions between an ‘internationalised’ knowledge (i.e. the molecular biology of Trypanosoma cruzi) that becomes autonomous (‘purified’). Particularly, Kreimer analysed how research on Chagas became common currency in the international knowledge market yet at the same time found its justification in the way of constructing a public issue (Ibid, p.12-13).

Similarly, the zebrafish constitutes an ideal case to revisit dynamics of internationalisation in a relatively new model organism and to understand how these
complex social dynamics intervene in processes of knowledge production and diffusion in science. However, unlike Kreimer’s Chagas case, the zebrafish is not an ‘autonomous’ model, but rather a ‘highly internationalised’ one. I am not interested in examining, as Kreimer did, the tension between international knowledge and local needs. Instead, I argue that complex dynamics of internationalisation can – and should – also be studied in fields of basic research or in models that are not necessarily connected to local circumstances such as a disease affecting rural population in endemic areas. By doing so, I hope to demonstrate the extent to which power dynamics are also present in what at first sight looks like harmonious global research ecosystems. This means that while my analysis focuses on South American zebrafish research, I want to ‘contextualise’ this region in the wider global scientific system that it takes part in. This takes me to adopt an ‘embedded multiple-case design’ (Yin 2003) whereby trends and patterns in South America are compared with those observed in other regional scientific communities (e.g. North America, Europe and Asia-Pacific). Next, I discuss in more detail aspects of zebrafish research that make it a highly interesting ‘model’ to study dynamics of scientific internationalisation in South American life sciences.

‘Pez cebra’: A promising and a fast-growing model organism in South America

During the fieldwork, I came across a group of researchers working on a promising model organism: the zebrafish; a one and half inches long tropical fresh-water fish originally from the Ganges region of India. As I was able to confirm after my second interview with a zebrafish researcher, the zebrafish has indeed become one of the fastest growing model organisms in terms of publications worldwide, surpassing in some cases well-established model organisms such as Drosophila (i.e. fruit fly) and Xenopus (i.e. frog) (see figure 2a) (see also Varshney, Sood, and Burgess 2015). An increasing number of researchers are adopting this little fish to study a wide range of biological and biomedical questions and many research centres across the world have established zebrafish labs (see figure 2b).
Its attractiveness is often justified by many features, among which the following stand out (Stewart et al. 2014; Kalueff, Echevarria, and Stewart 2014):

- High genetic homology to humans; humans share about 80-85% of genetic code with this fish.
- It is a sufficient physiological complex in-vivo model that reproduces quickly and abundantly.
- It has an external and transparent development that facilitates enormously experimental manipulation (i.e. researchers only need a common microscope to observe the development of embryos).
- It is space/cost-efficient when compared with other more traditional vertebrate models like mice or rats (1 tank = US$ 6.5 cents vs 9 rats = US$ 9 cents).
- In most cases, the choice for this model organism is said to vary according to the research questions. In this sense, zebrafish is thought to be an effective third-path between simple multicellular organisms and complex and expensive vertebrate models such as mice and rats.
While the use of zebrafish in scientific research has been growing steadily on the world-stage, in South America this growth has been unprecedented (Buske 2012; Gheno et al. 2016; Trigueiro et al. 2020). Users of the zebrafish as a research model in this region stress that its promise is mainly due to its economy allowing average laboratories, which often operate with small budgets and with less well-developed science infrastructures, to conduct world-class research (Allende et al. 2011, 33). This has translated into a remarkable increase of publications from South American researchers outpacing the growth rate of publications on other model organisms. This point is extremely important when we take into account the transformation process the life sciences underwent, becoming a more technology-driven field of research in recent decades, and which I discussed in the previous chapter. Thought the model increases the prospects of conducting high-quality research with more autonomy, this has not been translated into a decreasing importance of internationalisation judging by the remarkable growth of internationally co-authored publications (see figure 3).

Another feature that increases the relevance of the zebrafish as a model to study internationalisation dynamics is the existence of networks of scientists that aim to diffuse standard zebrafish research. By most accounts, the international zebrafish community is described as a strong community that has solid infrastructures and wide collaboration networks, often giving the impression of a global ecosystem where knowledge and resources are mobilised and exchanged without constraints. Yet in the case of South American zebrafish research, regional and international networks
constitute key mechanisms for laboratories to cope with the challenges of conducting research in a peripheral context and therefore are forged in a context of asymmetry.

Overall, given its unprecedented growth in South America and the peripheral characteristics of the countries of the region, the zebrafish constitutes an interesting case to study how complex dynamics of scientific internationalisation have influenced the construction of this little fish as a model organism, its diffusion across geographies and as well as its interaction with notions of research excellence.

**Research aim and questions**

As noted in the previous chapter, in South American life sciences, scientific internationalisation is a transformative and relational process driven by tensions in practices of resource exchange, knowledge transfer and research excellence. Therefore, the aim of this thesis is:

- To understand the transformative processes produced by internationalisation dynamics in contemporary South American life sciences.

**Sub-aims**

Using zebrafish research as a case study, I aim to:

- Investigate dynamics of dependency and empowerment present in the formation of this international scientific community and in practices of resource exchange.
- Examine the role that spatially bounded collaborative networks played in diffusion of zebrafish as a model organism in South America in comparison to other scientific regions.
- Understand the interaction between international mobility and notions of scientific excellence present in the South American zebrafish scientific community.
- Contribute to generate more insights into the combination of qualitative and quantitative methods in STS.

Given the research aims, the following questions guide this thesis.
Main research question

- How do dynamics of scientific internationalisation intervene in contemporary practices of knowledge production and diffusion in South American life sciences?

Sub-research Questions

- What has been the role of internationalisation dynamics in the standardisation of zebrafish as a model organism and in the construction of the international zebrafish community and its research ethos?
- Based on the experience of South American zebrafish researchers, to what extent are dynamics of dependency and empowerment present in practices of resource exchange and in the international infrastructures built to support such exchanges?
- What is the spatial structure of the zebrafish international collaboration network? What role have different geographical collaborative networks played in the diffusion of zebrafish as a model organism in Latin America?
- How are notions of research excellence constructed in the international zebrafish community and how do they interact with South American researchers’ international mobility trajectories?
- To what extent can quantitative and qualitative methods be combined in the social study of scientific internationalisation?

Next, I explain the ontological and epistemic foundations of qualitative and quantitative methodologies in STS and the implications, limitations and opportunities of combining these methods for the social study of scientific internationalisation.

Combination of methods: ‘Image’ and ‘Logic’ in STS

According to Wyatt et al. (2015), two rather contradictory quantitative and qualitative epistemologies have coexisted within STS. On the one hand, a ‘Mertonian’ or ‘Institutional Sociology of Science’, which focuses on structural phenomena such as the stratification of science and the development of specialities using quantitative methods. Quantitative approaches within STS, based on statistical analyses, surveys, large numerical databases and, quite recently, big data and network visualisations, all fall within the broader field of scientometrics.
On the other hand, the qualitative epistemology of STS finds its origins in the constructivist tradition of the 1970s and the development of the ‘Sociology of Scientific Knowledge’ (SSK). Emerging as a response to the normative perspective of the Mertonian sociology of science, the Bath School shifted the focus away from macro-level phenomena to micro-sociological processes in the 1980s (Wyatt et al. 2015). As a result, quantitative macro-level analyses of scientific papers were criticised for having a limited capacity of explanation of scientific practices at the micro level (Edge 1979). Instead, interviews, participant observation, focus groups and document analysis were considered suitable methods available to STS researchers to study these phenomena. Later on, STS moved to a post-constructivist phase, increasingly adopting perspectives from critical theory, feminist theory and post-colonial theory.

Each of these two epistemologies relies on different assumptions, levels and units of analysis (see figure 4). Scientometrics is based on the premise that the communication of research results is the main carrier of scientific knowledge, which makes publications the ‘building block of science’ (Van Raan 2005, 25). On the other hand, STS constructivist approaches consider science as a community-based belief system where the units of analysis are actors or collectives driven by a blend of socio-epistemic interests (Wyatt et al. 2015).

![Figure 4. The epistemic divide in STS. Adapted from Hinze and Glänzel (2017)](image)

As noted by Shrum et al. (2007, 11) the struggle between these two epistemic traditions in STS is reflected in Galison’s metaphorical contradiction between image
and logic. For Galison (1997, 23) the image tradition seeks to produce instances so well defined (i.e. a ‘golden event’) that could provide the basis for compelling explanations about a certain phenomenon without needing to invoke further data. The logic tradition, in contrast, relies on numerical and statistical demonstrations that would illustrate which events are significant. The formation of a hybrid tradition and the development of an interlanguage that would make the local coordination possible is needed to overcome this epistemic divide. Translating this analysis to STS, Shrum associates the image tradition with qualitative STS because it uses case studies as its ‘golden events’, whereas the logic tradition, he argues, is reflected in bibliometrics studies of S&T largely based on numerical and statistical demonstrations. It is not clear though what are the research design mechanisms that would sustain this interlanguage in STS. Ultimately, Shrum and colleagues’ proposal lacks a deeper discussion of the aspects of both tradition that become ‘traded’ in the attainment of a hybrid tradition.

Each tradition has its strengths and limitations. Take for instance the study of scientific collaboration. As noted by Subramanyam (1983), given the limited capacity of traditional methods (e.g. ethnographic observations, interviews and surveys) to capture the extent of scientific collaboration, bibliometric methods provide a convenient and non-reactive tool for studying this phenomenon. For Shrum (2007, 8–9), however, the more severe limit of co-authorship is that such data cannot generate insights into the internal dynamics of collaboration and, in this sense, co-authorship as a form of evidence of cooperation in science, is divorced from social organisation and context. Alternatively, qualitative STS studies of collaboration produce detailed narratives of projects, research teams and institutions, and provide valuable theoretical guidance that help identify important social processes. Yet at the same time, although being able to illuminate both structural and cultural aspects, qualitative methods are unable to provide a systematic assessment of the relative importance of one process over the other.

Overall, even though both approaches share a deep commitment to the empirical study of S&T, they rely on different epistemological assumptions (Wyatt et al., 2015) and the intellectual distance between the two has been widening more and more over the last decade (Leydesdorff 2001; Leydesdorff and Milojević 2015). However, recent discussions about the responsible use of scientometrics in research evaluation have shed some light on the opportunities and limitations of building a
bridge between both traditions, which could in turn help inform prospects for developing mixed-methods approaches in STS. In what follows, I explain the basic aspects of this discussion.

At the most basic level, scientometric indicators are quantitative representations of certain scientific and technological activities (Barrere 2010). As a measurement instrument, every indicator performs a function of ‘representation’, which follows the characterisation of the concept one is trying to approach. Characterising a concept implies defining its characteristics or dimensions whereas the ‘procedures’ refer to the methods we employ to measure whatever it is we are trying to measure (Cartwright and Runhardt 2015) (see figure 5).

![Figure 5. Measurement process in bibliometrics](image)

While the academic community can provide the conceptual basis for the development of indicators, through characterisations drawn from theories and empirical observations, in most cases it is standard practice to start without a theoretical framework (Van Raan 2005; Reale et al. 2012). This responds to a long-held vision in scientometrics by which the adoption of a single theory to guide the making and use of indicators is considered worse than the absence of any explicit theory (Holton 1978). Based on a positivist and reductionist approach, scientometrics assumes there is an independent reality – i.e. one existing outside the research subjects –, which is waiting to be discovered (in the example laid out in figure 5, that would be scientific collaboration). Considering the research object of the present thesis, a consequence of this vision is the frequently repeated mantra that internationalisation is, and has always been, an intrinsic component of science (see Chapter 2). Therefore, the job of indicators and scientometrics in general, is to show where internationalisation is.
As it is well-known, in the field of information sciences, scientometric indicators are regarded as a vehicle for the efficient allocation of resources, which makes them one of the most utilised tools in research management and evaluation (Clark 1985). However, because they have the power to ‘define the world’, recently the validity of such representation has been put into question among scientometricians. The term ‘contextualised scientometrics’ has been put forward by Waltman (2019) in order to express the importance of context when designing and interpreting scientometric indicators. Contextualised scientometrics allows the user to understand the limitations and biases inherent to indicators, so that they are not misinterpreted due to technical and conceptual assumptions on what the indicator is measuring (see Robinson-Garcia and Rafols 2020).

Moreover, Waltman warns that the validity of the representative power of scientometric indicators depends on the level of analysis on which the evaluation is being conducted. At the macro level, he notes, indicators should guide the evaluation while at the micro level there exist particularities that require a combination of quantitative and qualitative methods. That is, at the macro level, experts view the world through indicators. Hence, they not only support the evaluation, but they ‘make it possible’. In other words, they define the phenomenon. Furthermore, according to Leydesdorff (2018), in order to improve research evaluations, experts should not only be informed by the level of analysis, but they should also be ‘theoretically informed’, which requires opening the black box of the system under study. This constitutes a key step forward in the ontological and epistemological basis of scientometrics, which could be applied to STS so that indicators perform their role as described by van Raan (2005); that is, to become effective research tools for the social study of science.

How can this be achieved in practice? In their study of the structure of scientific collaboration, Shrum and colleagues (2007) proposed an ‘inter-language’ that combined case studies with qualitative and quantitative analysis of interviews. However, even though they employed quantitative methods, scientometric or bibliometric techniques were discarded. Because of this, I argue, they failed to generate a ‘dialogue’ – to use a similar expression – between the two epistemic traditions in STS. In this research project, I combine qualitative and bibliometric and quantitative methods. However, my goal is not to develop a ‘hybrid language’ as suggested by Galison (1997). Instead, I argue that it is better to let each method ‘speak for itself’, to provide insights about the dynamics being investigated at different
levels. Qualitative methods like interviews can provide in-depth insights about specific cases (images) that are relevant for the 'logical' observation of international dynamics in its various forms (Liscovsky Barrera 2018). In this sense, my research structure, in terms of the methods I employ, is not hierarchical as suggested by Greene, Caracelli, and Graham (1989) but complementary as suggested by Bryman (2006).

Overall, I consider the study of scientific internationalisation as requiring insights from both quantitative and qualitative methods. I argue that in adopting a mixed-method approach in STS, there has to be qualitative research that gives account of the experiences and narratives of the subjects being studied, and which should guide the characterisation, representation and procedures of quantitative techniques employed to study social dynamic of science, and fill the gaps left by large-scale quantitative analyses.

Research structure

This research project proposed to study internationalisation dynamics by combining methods found in qualitative and quantitative STS while adopting a multi-level perspective that focuses on micro and meso levels of analysis to investigate complex dynamics of scientific internationalisation in South American life sciences.

Therefore, the structure of the research for this thesis was as follows:

- **Overseas fieldwork**: from May to September 2018, I travelled to Argentina, Chile and Uruguay and carried out fieldwork, including semi-structured interviews and ethnographic observations, with the aim of studying contemporary dynamics of scientific internationalisation in these countries.

- **Research visit – Quantitative data collection**: from September to November 2018, I did a research visit to the Centre for Science and Technology Studies (CWTS) of Leiden University. There I received training on scientometrics and bibliometrics, and I was able to use their curated bibliometric databases. As a result of this, I designed a procedure for collecting bibliometric data referred to zebrafish. I collected more than 28 thousand publications on zebrafish research and more than 2 million publications authored by zebrafish researchers, which I used to extract their affiliation data and reconstruct their international mobility trajectories.
• **Analysis:** back in Edinburgh, from January 2019 to July 2020, I analysed data extracted from the interviews, collected documents and notes from ethnographic observations. I also conducted quantitative and SNA on the bibliometric dataset I compiled. The analyses focused on both macro and micro aspects of internationalisation dynamics intervening in processes of knowledge construction and diffusion taking place in zebrafish research.

I decided to organise the empirical analysis into three chapters, each one dealing with a specific transformative dynamic of scientific internationalisation. Together, the three empirical chapters aim to cover key transformations taking place in processes of knowledge construction and diffusion in zebrafish research. In particular:

- **Chapter 5** addresses on the one hand the construction of zebrafish as a model organism, the international zebrafish community and its research ethos from a socio-historical perspective. One the other hand, by focusing on the experiences of South American zebrafish scientists, I unpack dynamics of dependency and empowerment present in practices of resource exchange as well as the barriers and reactions to international infrastructures built to support these exchanges.

- **Chapter 6** studies the role of spatial collaborative networks in the diffusion of zebrafish in South America *vis-à-vis* other scientific communities. I investigate the extent to which the adoption of zebrafish as a model organism in South America relied on collaboration with networks of experienced international collaborators. In addition, I closely examine the nature and significance of these collaborative linkages for South American zebrafish researchers.

- **Chapter 7** looks into the relationship between internationalisation and research excellence. Based on notions of excellence commonly found in model organism communities, I first investigate how practices of biological data curation at the zebrafish community shape notions of excellence in this field of research. Second, I study how the mobility trajectories of South American zebrafish researchers interact with their contributions and visibility within the zebrafish knowledge infrastructures.

At the beginning of each chapter, I discuss the most updated theoretical discussions that frame the focus of the chapter and whose general lines I have already introduced in Chapter 2. Following this, I provide a detailed description of the
techniques of data collection and analysis I used – including specific methodologies I developed – to answer the research questions asked in those chapters. In general, because of the complex and multi-level dimensions of scientific internationalisation, I consider the study of scientific internationalisation as requiring insights from both quantitative and qualitative methods. In this sense, one of the major advantages of embedded multiple-case designs is the variety of methods that can be used (e.g. surveys, interviews, ethnography) thus turning it into a bridge between quantitative and qualitative methods (Yin 2003; Morgan 2015). Accordingly, I make use of bibliometric techniques, SNA, statistics as well as qualitative methods including interviews, ethnographic observations and document analyses.

**Qualitative data**

**Interviews: sample description**

During the fieldwork in Argentina, Chile and Uruguay, I conducted semi-structured interviews with more than 30 heads of laboratory and researchers, mostly male, working in various disciplines within the life sciences (e.g. plant research, agriculture, genetics, biomedicine and developmental biology) and from different types of institutions (e.g. private and public universities, research centres and laboratories). The sample of interviewees also includes researchers both working in leading and internationally recognised institutions and in less internationalised research centres and ill-equipped labs. This allowed me to control for the effect of working environments in the vision of internationalisation held by scientists.

Moreover, because the majority of the interview participants are well-established researchers, their accounts of current experiences of internationalisation were mostly connected to the experiences of their PhD students and postdocs. However, almost all of the interviewees worked or studied abroad at the beginning of their careers; a period that they often recalled in positive terms. This did not influence their opinion of knowledge acquisition via international mobility because for them such process continues through their students and early career researchers working in their labs but also throught the collaboration networks that are forged as a result of these trajectories.

In addition, I also interviewed various policy makers, research managers and social researchers and one European life scientist from The Netherlands, a leading Global North country in zebrafish research. This last interview coincided with my
research visit to CWTS of Leiden University during the second part of the fieldwork. In total, I conducted 46 interviews – all in person, except three, which were conducted via Skype – that helped me to collect a large amount of rich and in-depth data of internationalisation dynamics in South American life sciences. All of the interviews were in Spanish except the interview with the Dutch scientist, which was conducted in English.

**Selection criteria and interview questions**

The goal of the first interviews (May-July 2018) was to obtain a first-hand appreciation of what internationalisation looks like beyond abstract concepts or quantitative indicators, and bring relevant contexts into focus (e.g. geographical, disciplinary, institutional and biographical). In these conversations, I asked my interviewees about their experiences of studying or working abroad, their participation in international research projects and their motivations for engaging in these practices. Using existing publications, I was also able to inquire about specific research conducted jointly with international partners, the background that led to these collaborations, how research work was organised, and the lessons they learned in retrospective. Lastly, I asked their opinion about research evaluation practices in their countries and how they saw these practices affect their work.

Access to a majority of researchers in this first group of interviewees was possible through a senior scientist – Aída E. Sterin Prync – who has a long record of experience in the life sciences in both private and public sectors in Argentina. From there, I followed a snow-ball sampling strategy that led me to cover various areas of research. Criteria for selecting interview participants include their work with different types of model organism such as pigs, plants, chickens, mice, rats and the aforementioned zebrafish.

In the second group of interviews (July- September 2018), I concentrated mostly on zebrafish researchers. In this case, I prioritised those researchers that were part of the Latin American Zebrafish Network (LAZEN). As with the first group, the goal of the zebrafish interviews was to collect experiences and visions of scientific internationalisation in this community. However, I also sought to gain knowledge of zebrafish research and their views on the organisation of the international zebrafish community through communal infrastructures as well as practices of resource exchange through informal collaborative networks. I wanted to understand how South
American scientists working with this model initiate, organise and ultimately understand processes of scientific internationalisation in this community.

**Thematic analysis**

To analyse the interviews, I used thematic analysis; a method that aims to identify patterns of themes or subjects in the interview data, by staying close to the participants’ perspectives (Clarke and Braun 2015). Interviews were first transcribed and while reviewing the transcripts I took preliminary notes to identify potential topics. I then identified specific extracts that resulted interesting and I assigned codes to them. Following this, I searched for patterns across the different transcripts (i.e. repeated codes or similar content based on the notes I took) and I proceeded to group the codes into different subjects. Lastly, I reviewed the themes to make sure (1) the grouped codes were consistent with the themes I identified and (2) that themes were representative of internationalisation dynamics.

In particular, I analysed the interviews according to the following themes:

- *Practices of internationalisation*: these include experiences of studying or working abroad, scientists’ participation in international research projects and their motivations for engaging in these practices.

- *Practices of resource exchange*: I used a sample of researchers’ own publications during the interviews to inquire about specific research work conducted jointly with international partners. In these conversations, practices of resource exchange were mentioned prominently when researchers explained to me the background of these collaborations and how research work was organised.

- *Notions of research excellence*: these include researchers’ visions on evaluation practices in their own countries and how they thought these practices affected their careers and research work.

- *Zebrafish community*: codes belonging to this subject refer to researchers’ testimonies on the organisation of the zebrafish community including, international research infrastructures, congresses, seminars and their participation in research networks.

Across the themes, I was also able to record notions of asymmetry, dependency and empowerment. That is, these themes not only allowed me to unpack specific elements of scientific internationalisation in South American life sciences (see
Chapter 3), but also to inquire further on the problematic dimension of internationalisation dynamics in zebrafish research (Chapters 5, 6 and 7). In this sense, thematic insights extracted from the interviews helped me to explore with more detail certain aspects left unclear by the quantitative analysis. Because of this, the procedure explained above (i.e. coding, identification and review of themes) was not always linear, as sometimes I went back to the transcripts to identify additional subthemes.

**Ethnographic observations and documents**

In addition to interviews, I also collected data through ethnographic observations and document analysis. I had the opportunity to conduct two ethnographic observations in a zebrafish laboratory in Argentina. The first observation was conducted in July 2018 when I was interviewing the first zebrafish researchers. The second observation was conducted in late August that same year – by then I had already gained some knowledge of zebrafish research. During both visits, I wrote down some descriptions and reflections of what it is like working in a zebrafish lab and ‘co-existing’ with the fishes. I was also introduced to the technicians working in the research facilities who kindly explained to me how fishes are taken care of. These notes helped to contrast the conditions and resources South American researchers often work in with existing descriptions of zebrafish labs and facilities (i.e. in guides or standard manuals). A clear example of this comparison are fish tanks and practices of specimen acquisitions described in Chapter 5.

Lastly, I also collected a number of documents that helped me to re-construct the history of zebrafish at the global scale. These documents include scientific papers and personal accounts by zebrafish pioneers, which I used to reconstruct the history of the standardisation process of zebrafish as a model organism. When analysing the material features of the zebrafish community (i.e. its resource and knowledge infrastructures), I also relied on manuals and other similar documents describing guidelines and protocols for exchanging stocks via existing centralised international infrastructures.

The use of documents as a source of data collection also include peer-reviewed publications on zebrafish research. However, in this case, I applied quantitative analysis to analyse dynamics of scientific internationalisation reflected in the scientific literature. Unlike interviews or ethnographic observations, the analysis
of large volumes of literature allowed me to study internationalisation dynamics at meso and macro levels of analysis. Reaching this point, it may be worth explaining why I decided to use documents as a method of data collection. Even though I conducted more than 40 interviews with scientists and policy makers in Argentina, Chile and Uruguay, and even though the Latin American zebrafish community is rather small, I could not interview a large cohort of people. A survey was not an option for a number of reasons: (1) it is time consuming and I was already collecting data from interviews, (2) response rates among researchers are usually low, and (3) it can be a quite expensive technique. In turn, I realised that if I were able to create a comprehensive collection of scientific papers on zebrafish, I would be able not only to observe the evolution of zebrafish research but also study patterns and structures of international collaboration and mobility. For this, I made use of quantitative techniques from bibliometric and social network approaches.

Next, I explain basic concepts, terminology and techniques commonly used in bibliometrics and SNA to introduce readers that might not be familiar with these methods, which are crucial for understanding the more advanced methods introduced later in the thesis.

**Bibliometrics: data sources and metadata**

Scientometrics proposes to study science mainly as an informational and communicational process (Hess 1997). For its part, bibliometrics, the most prominent subfield of scientometrics, entails the application of statistical methods to scientific papers, books and other media of communication (Pritchard 1969, 349). In what follows, I explain basic concepts and techniques used in bibliometric research that are relevant for this thesis.

**Data sources: bibliometric databases**

Bibliometric or citation databases are archives that contain information on scientific publications (e.g. papers, conference proceedings, book chapters, reviews, etc.), including citations, abstracts and even full texts. As discussed in Chapter 2, the launching of the Science Citation Index (SCI) by Eugene Garfield in 1964 was a major event in the development of bibliometrics, becoming the world’s first large multidisciplinary citation database (Salini 2016).

At present, the most relevant bibliometric databases include:
The Web of Science (WoS): the successor of the aforementioned SCI; acquired by Thomson Reuters in the 1990s and currently owned by Clarivate Analytics. The WoS Core Collection has a coverage of more than 21 thousands journals, books and conference proceedings and more than 79 million records in life sciences biomedical sciences, engineering, social sciences, arts and humanities (Clarivate 2020).

Scopus: owned by Elsevier, it has a collection of more than 77 million records distributed, over 25,100 titles from more than 5 thousand international publishers and covering a wide range of disciplines: life sciences, social sciences, physical sciences and health sciences (Elsevier 2020).

Google scholar: a free access search engine provided by Google with a wider coverage than WoS and Scopus but with a poorer data quality (Salini 2016).

Besides these multidisciplinary repositories, alternative bibliometric data sources are databases that have a specific disciplinary focus, often offering a better coverage in their fields. Examples include PubMed (biomedicine), MathSciNet (mathematics), Chemical Abstracts (chemistry) and COMPENDEX (engineering).

Lastly, as explained in Chapter 3, model organism communities have built their own knowledge cyberinfrastructures. These community databases not only curate and store genomic and genetic information relative to their organisms, but they also curate scientific literature relevant to these scientific communities. In the case of zebrafish, the Zebrafish Information Network (ZFIN) acts as the centralised online repository containing information on zebrafish research worldwide. Chapter 7 provides more detail about the practices of data curation taking place in this database.

Following criteria of access, scope and coverage, all of the above databases are considered ‘international’. Next to these international databases, regional and national databases are additional sources of bibliometric data. In Latin America SciELO, Redalyc or LATINDEX are well-known examples of regional databases.

In this thesis, I make use of Scopus as the primary source of bibliometric data. Reasons for selecting this database are twofold. On the one hand, though the research output of scientists from peripheral countries tends to be generally underrepresented in international bibliometric databases such as WoS and Scopus (Shrum and Campion 2000), previous studies have shown that Latin American life scientists reported to publish primarily in journals included in these major
bibliographical indices (Jonkers and Cruz-Castro 2013). On the other hand, information on authors’ affiliations in Scopus dates backs to 1996 whereas WoS only had this information from 2008 onwards. Since my interest was assessing co-authorships networks since the publications of the Big Screens results in 1996, the Scopus database proved ideal. Access to this database was provided by CWTS during the time I conducted a two-month research visit (September-November 2018).

**Metadata and levels of analysis**

Scientific publications are more than just text: they contain both data (e.g. the content of the publication itself) and metadata. The later can include author names, affiliations, citations, keywords or curated annotations associated to each publication. This metadata is relevant because it allows observing, and ultimately measure, social dynamics and interactions taking place in scientific production.

Take for instance, the following paper published in *Neurology of Stress*:

*The effect of an adverse psychological environment on salivary cortisol levels in the elderly differs by 5-HTTLPR genotype*

Marie-Laure Ancelin a,b,c, Jacqueline ScaI d,a,b, Joanna Norton a,b, Karen Ritchie a,b,c, Anne-Marie Dupuy a,b,c, Isabelle Chaudieu a,b,c, Joanne Ryan a,b,c

*Institutes:*
- a INSERM, Marseille, France
- b University of Marseilles, Aix-Marseille, France
- c Center for Clinical Brain Sciences, University of Edinburgh, UK
- d James Cook University, School of Medicine, Queensland, Australia

**Figure 6. Scientific paper example**

Besides its content, the paper contains information about the authors and their institutional affiliations. For instance, paper in figure 6 is co-authored by seven authors from different institutions and countries, namely France, the UK and Australia. Each of these elements constitute distinct units of analysis at different levels:

- **Individual or author level:** authors listed in the publications.
- **Meso or institutional level:** the institutional affiliations listed in the publications.
- **Macro or country level:** the country affiliations listed in the publications.

The level of aggregation will depend on the chosen unit of analysis. For instance, if a ‘meso level’ of analysis is preferred, then one can collect additional information about the country or region of each institution – this information rarely
varies across time. However, if one decides to use authors as out unit of analysis, then the task becomes more complex because in a great number of cases – and especially in the hard sciences –, authors often have multiple affiliations. The possibility to collect consistent additional metadata on the micro level is therefore more limited.

In addition to information about authorships, bibliometric databases include information about selected keywords, funding and curated annotations. The latter can be produced by the databases themselves (e.g. scientific subject classifications) or provided by external databases or repositories (e.g. Medical Subject Headings developed by the National Institutes of Health).

**Bibliometric approaches to scientific internationalisation**

**Co-authorships: a proxy to measure scientific collaboration**

In bibliometrics and information science in general, scientific collaboration is considered to take place when two or more researchers have co-authored a research document (usually a scientific paper published in a recognised journal). From a bibliometric perspective, therefore, co-authorships in papers are widely considered a suitable proxy for measuring scientific collaboration (Barnett, Ault, and Kaserman 1988; Melin and Persson 1996). In the 1950s, Smith was the first to propose this proxy measure (Smith 1958) and in the 1960s, the work of de Solla Price (1963) provided empirical evidence on the increase of multi-authorship in science. Since then, bibliometric studies of collaboration have proliferated.

Some authors (Laudel 2002; Sonnenwald 2007), however, have criticised quantitative studies of collaboration, noticing how bibliometric methods rest on assumptions that leave aside certain important issues of collaboration, in particular: 1) not all authorships are the result of collaborative actions, and 2) co-authorship is not the only form of collaboration in research. In this regard, Katz and Martin (1997) emphasise the importance of establishing a conceptual distinction between collaboration and co-authorship – the latter being one form of collaboration.

As with the units of analysis explained earlier, scientific collaboration can be studied at different levels: *micro*, *meso* and *macro*. In this sense, the lack of

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7 See Chapter 2 for more detail on the extensive use of co-authorships in bibliometrics analyses.
representation of co-authorships described by Laudel and Katz and Martin rather applies to micro or ‘intramural collaboration’. Extramural collaboration, international collaboration in particular, is usually well acknowledged (Glänzel and Schubert 2005). Therefore, the analysis of co-authorships at either micro or macro levels provides a good proxy to study spatial dynamics in scientific collaboration.

In bibliometrics, some of the most frequently used measures of co-authorship collaboration include:

- Number and share of co-authored papers in all papers. This measure is sensitive to the size of the publication output of an author, institution or country.
- Share of papers with a given partner in all co-authored papers.
- Salton’s (cosine) measure as an indicator of collaboration strength:

\[ r_{ij} = \frac{P_{ij}}{\sqrt{P_i \cdot P_j}} \]

where \( P_{ij} \) is the number of joint papers and \( P_i \) (\( P_j \)) the number of all papers of the two units.

With the advancements in network theory and improved computational capacities, new measures have been included in bibliometric analyses of collaboration and nowadays co-authorship networks are the largest publically available form of social networks (Kumar 2015). The most relevant network measure for the present thesis are explained in the next section discussing the social network approach to bibliometrics.

**Affiliations: an alternative source to reconstruct mobility trajectories**

Measuring scientific mobility is a highly complex and costly task and very few institutions and governments have been able to track the international trajectories of their research workforce in a systematic way (Franzoni, Scellato, and Stephan 2015). Bibliometric databases provide an alternative source of data to analyse mobility trajectories by tracking the changes in the researchers’ affiliations across time (OECD 2013). However, researchers’ affiliations are not a static attribute. Scientists have career paths in which the change institutions and even countries is highly frequent. While changes in institutional affiliations, as reported on publications, are not always related to actual changes in scientists’ location, they can nevertheless serve as a
reasonably good proxy measure of mobility and they provide a more comprehensive coverage across all countries than surveys (Appelt et al. 2015).

The most common strategies for analysing mobility trajectories include Event History Analysis (EHA), Sequence Analysis (SA) or Multichannel Sequence Analysis (MCSA). EHA focuses on the events taking place in the life course of individuals and aims to predict the time it takes for an event (e.g. divorce, graduation, etc.) to occur. Therefore, the type of data EHA methods employ are longitudinal records of an individual’s lifelong events (event history) and their survival time, understood as the time it takes for that event to occur from a well-defined event (Allison 1984; Broström 2016). However, a major problem with research on life trajectories is that individuals have different sequences of event speeds. Because of this, EHA methods require heterogeneous trajectories which reduces the size of the datasets (Abbot 1992). Alternatively, SA methods operationalise the concept of life trajectory as a sequence of events and seeks to uncover patterns of trajectories rather than looking for causal inference like EHA does. By taking a “narrative approach” to trajectories (Abbot 2001), SA does not make assumptions about the processes that generate these trajectories and instead allows one to visually inspect and compare life-course patterns across time and space.

Nevertheless, a key limitation of both EHA and SA is that they are limited to observing one dimension at a time. That is, they do not consider the multidimensionality of life trajectories. In this sense, MCSA is a more sophisticated alternative because it enables researchers to describe individual trajectories on several dimensions simultaneously (Gauthier et al. 2010). In MCSA, each individual is associated with two or more distinct channels, each tapping a distinct life trajectory within a specific sphere (e.g., occupation, family, housing, location, health) by means of a specific alphabet (Ibid: 9). For a more detailed description of these methods, I recommend Abbot (2001) and Gauthier et al. (2010).

While MCSA is a more sophisticated and comprehensive methodology to analyse mobility trajectories, it is not suitable for analyses based on bibliometric data due to the existence of authors’ multiple affiliations. Multiple institutional affiliations is a phenomenon that poses importance challenges when it comes to measure geographical mobility (Robinson-Garcia et al. 2019). When analysing mobility trajectories based on bibliometric data researchers are faced with a decision to discard publications that express multiple institutional affiliations in order to fit the data
into their models (Appelt et al. 2015). However, multiple institutional affiliations are a common aspect of researchers’ career trajectories, particularly in the hard sciences. Researchers might travel abroad in the form of short-term visits to conduct specific experiments and/or to receive training. A key indicator of these mobility experiences are the double or multiple affiliations recorded in the most common output of these knowledge transfers, a published paper. Therefore, ignoring multiple affiliations means neglecting crucial aspects of geographical mobility in science and of knowledge diffusion and circulation.

In spite of its advantages vis-à-vis EHA or SA, MCSA does not allow computing multiple and different events within one channel or track. This is a critical point when bibliometric data is being used to reconstruct researcher’s mobility trajectories. For instance, as part of his or her mobility trajectory, a researcher might experience a rupture with his/her country of origin (e.g., the publication only includes the affiliation with the hosting institution) which could be interpreted as a migration type of event. However, within the same year, the researcher’s publication record features a link between the sending and hosting institution (e.g., the publication includes a double affiliation) which could be interpreted as a short-stay. These two types of events are taking place simultaneously within a same channel: geographical mobility.

Based on the above, my analysis of international mobility will not seek to build a causal model of mobility events (e.g. using EHA or SA) nor will it analyse mobility trajectories ignoring crucial aspects of this phenomenon (e.g. using MCSA). Instead, I will make use of alternative methodologies to classify mobility trajectories based on bibliometric data (Sugimoto et al. 2017; Robinson-Garcia et al. 2019). This method will also allow me to study the interaction of international mobility with researchers’ contributions to community knowledge infrastructures. Chapter 7 provides more detail of the methodology and the data collection and structuring procedure affecting the study of international mobility of zebrafish researchers.

**SNA and Bibliometrics**

**The network approach**

The main goal of SNA is detecting and interpreting patterns (or structures) of social ties among actors. As such, the network approach consists of looking at the actual relationships that exist between actors, rather than relationships based on institutional definitions or common attributes such as living in the same household or country,
working in the same company, having the same religion, belonging to the same social class, etc. (Hennig et al. 2013).

A network is composed by a set of nodes (also referred as *vertices*) connected by a set or sets of lines (also known as *edges, arcs* or *ties*). Nodes can be actors (e.g. people, organisations, countries) but also many other things (e.g. genes, words, cities, etc.). Likewise, the conceptualisation of ties connecting actors can vary depending on the research focus (e.g. friendship, economic transactions, migration, cooperation, conflict, etc.). Networks can be represented visually using graphs or *sociograms* (see figure 7).

Network data is commonly handled in ‘adjacency matrices’, a terms that comes from graph theory and which refers to pairs of vertices that are *adjacent* or not in the graph. In figure 8, each row and each column represent a node (row 1 & col = node 1…). The value 1 is present when there is a tie between a pair of nodes; the absence of tie is 0. In this case, nodes are not connected to themselves, so 0 is displayed in the matrix’s diagonal. This means that the adjacency matrix is ‘symmetrical’ around its diagonal. In other words, the top half of each matrix is identical to the bottom half. Alternatively, network data is stored in *edgelists* where every line is an edge connecting a pair of nodes (*ego* and *alter*).
Collaboration Networks

The network approach in bibliometrics has had many applications, including citation networks, co-word analyses and, in the case of collaboration, co-authorship networks (for a thorough review, I recommend White 2014). In a co-authorship network, a node represents an author, institution or country, and the edges co-authorships in one or more papers.

Although the use of co-authorships to measure research collaboration has been a subject of significant interest since the 1960s, understanding research collaborations from the lens of social networks is a fairly young research area, which kicked off with the seminal work of Mark Newman in the early 2000s. Newman was the first to apply SNA methods to investigate the macro and micro characteristics of large co-authorship networks. In his view, a co-authorship network is as much a network depicting academic society as it is a network depicting the structure of our knowledge. His work examined the social structures of scientific collaboration aiming to reveal the mechanisms that shape the scientific community; in particular: how fragmented or cohesive the knowledge community is, or who are the best connected authors in that network (power dynamics). Newman’s studies (2001a; 2001c; 2004) opened the floodgates for other studies in co-authorship networks and provided a template of key measures to identify patterns of collaboration, centrality and cluster formation (White 2014).

Types of network data

Collaboration takes place when at least two researchers co-author a paper. When it comes to fill in the authorship matrix or edgelist, we take into account the number of papers a pair of researchers have co-authored in total. Because of this, co-authorship data is said to be weighted. The weight provides a measure of the strength of the collaboration tie.
Besides being weighted data, co-authorship data is undirected because co-authorship is a simultaneous reciprocal co-occurrence phenomenon. It happens at the same time for all authors sharing that publication. In other words, it is not dependent on subjective nominations by the authors.

**Counting methods**

Another aspect determining the construction of co-authorship networks is the counting method, which distinguishes between two options:

- **Full or whole count**: it assigns the same weight to all the authors listed in the publication.
- **Fractional count**: the co-authored publication is assigned fractionally to each of the co-authors, with the overall weight of the publication being equal to one. Hence, in the case of fractional counting, each publication has the same overall weight (see figure 9).

![Figure 9. Counting method procedures for bibliometric co-authorship networks.](image_url)

**Measuring centrality and power**

From a SNA perspective, power is relational. This means that power is regarded as phenomenon resulting not necessarily from the attributes or resources held by an actor, but from his or her interactions with other actors. The power actors have in a

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8 Figure 9: adapted from Eck and Waltman (2018).
network is therefore derived from their favoured positions in the patterns of ties. However, this does not mean that actors’ individual attributes are ignored in the analysis, but they are rather considered in the context of relationships (Hanneman and Riddle 2005).

There are different measures used to capture notions of centrality, power and the distribution of power across actors. Next, I describe three of the most relevant measures of centrality applicable to research on scientific collaboration.

**Degree centrality**
The most basic and common measure of network centrality is ‘degree centrality’. According to this measure, actors are central if they have many direct ties (in our case, many collaborators). Given an adjacency matrix $A$ and $\text{deg}(i)$ the degree of node $i$, the degree centrality $c_i^{\text{DEG}}$ of node $i$ is defined to be the degree of the node (Sun 2011):

$$c_i^{\text{DEG}} = \text{deg}(i)$$

In practical terms, the degree centrality can be interpreted as:
- Direct access to more collaborators and more resources.
- Lower dependency on single actors or alternative ways to satisfy their needs.
- Direct influence on many other collaborators.
- Act as third parties to control resources between (groups of) collaborators.

In addition to measuring the degree of a node, centrality can be computed as a network-level property. Known as ‘centralisation’, this measure computes the (unequal) distribution of node centrality scores across actors within a network (i.e. the concentration of power). A highly centralised network indicates therefore a small group of highly-centralised nodes (core) surrounded by a large group of peripheral nodes (periphery).

**Weighted degree centrality**
Similarly, a node’s weighted degree centrality takes into account its degree score but pondered by the weight of each edge. In doing so, it takes into account the sum of the weight of the edge. Actors with a higher weighted centrality score are central because they collaborate many times with many collaborators. Therefore, this measure considers the strength of collaborative ties when identifying central nodes in the network under the assumption that authors who have written many papers together
know one another better on average than those who have written few papers (Newman 2001a, 13).

**Betweenness centrality**

Lastly, *betweenness* centrality provides an estimation of how a central a node is to the extent it plays the role of a broker (i.e. a compulsory intermediary or bridge) between otherwise separated members of the network. To calculate this, it takes into account the number of *geodesic paths* (i.e. the shortest path between a pair of vertices) between nodes. Therefore, according to this measure, the more people depend on a researcher to make collaborators, the more powerful that researcher is. On the contrary, if two authors are connected by more than one geodesic path, and that researcher is not on all of them, then that same researcher loses some power.

\[
g_{jk}^{\text{path}} \quad g_{jk}^{\text{path}}\]

The betweenness centrality of a node \(i\) to be an intermediary between \(j\) and \(k\) is defined by the probability \(\frac{g_{jk}^{i \rightarrow \text{path}}}{g_{jk}^{\text{path}}}\) where:

- \(g_{jk}\) is the number of geodesic paths (shortest paths) connecting \(j\) with \(k\).
- \(g_{jk}^{i \rightarrow \text{path}}\) is the number of geodesic paths connecting \(j\) with \(k\) passing through \(i\).

**Network density and giant components**

**Density:**

Density is a measure of the network’s cohesion. That is, it reflects how cohesive the nodes in a network are. The density score indicates the proportion of all possible ties that are actually present in the network. In non-directed graphs like co-authorship networks, the maximum number of ties possible is \(n(n - 1)/2\). In valued graphs (i.e. weighted), the density expresses the average strength of ties across all possible ties.

**Giant components:**

According to Newman, most scientific networks exhibit a giant component which is defined as “a large group of individuals who are all connected to one another by paths of intermediate acquaintances” (Newman 2001a, 407). The size of the giant component matters, as it could reveal how cohesive or fragmented a network is (see also Otte and Rousseau 2002; Börner et al. 2005). In various research fields, these components comprise roughly 80 to 90 percent of scientists under study.
Figure 10. Average distance between pairs of scientists in the various networks, plotted against average distance on a random graph of the same size and degree distribution. Source (Newman 2001c, 12)

Figure 10 shows the average distance between pairs of scientists in different communities. Newman found that the typical distance between a pair of scientists is about six; meaning there are six degrees of separation in science, just as there are in the larger world of human acquaintance. Even in very large communities, such as the biomedical research community, Newman noted that it takes an average of only about six steps to reach a randomly chosen scientist from any other, of the more than one million who have published. He conjectured that this has a profound effect on the way the scientific community operates.

A mixed-method approach in practice: key concepts and methods

In the analyses of this thesis, I address a series of concepts that are key for understanding contemporary dynamics of internationalisation in zebrafish research. To study them, I use a mixed-method approach that brings together quantitative and qualitative techniques in a complementary fashion.

Power dynamics

When I talk about the ‘power dynamics’ of internationalisation, I adopt a ‘spatial’ perspective to the concept of power. I consider power as the concentration of expertise and resources in specific places of scientific practice, most notably rich countries. Power therefore is a spatially bounded attribute, which actors can possess simply by means of their geographical origin. However, from this perspective power
is also relational in as much interactions between geographically distant actors (e.g. via transnational collaboration and/or international mobility) often allow accessing such expertise and resources.

This notion of power is very much present in the classical diffusionist thesis (see Chapter 2) (Basalla 1967) as well as in more recent interpretations (Wagner and Leydesdorff 2005; Leydesdorff and Wagner 2008; Glänzel, Schubert, and Czerwon 1999). It is also closely related to the concept of the ‘geography of science’ (Olechnicka, Płoszaj, and Celińska-Janowicz 2018), which holds that the uneven distribution of the dynamics of research internationalisation create a hierarchical structure that is accompanied by a functional dimension. In other words, the structures formed by scientific collaboration serve particular functions such as establishing scientific hierarchies or increasing the quantity and quality of scientific enterprise. Therefore, I understand power as a product of the uneven geographical distribution of expertise and material resources, including ideas, techniques, trained workers, funding, equipment, and so on.

**Dependency**

The other concept that I mention frequently is that of ‘dependency’, which derives from the power dynamics of space. The existence of hierarchies in the geography of science means some actors are more dependent than others are on collaboration networks and international mobility. This dependency is not only a motor of knowledge production in the hierarchical global scientific collaboration network, but it is also a vehicle of diffusion. Through these networks of mobility and exchange, knowledge, ideas and expertise diffuse within and across the spaces of scientific practice. Here too the location of actors matters greatly and is a subject of increasing debate. In contemporary network diffusion studies for instance, there exist a confrontation between models that stress the importance of local networks and those that emphasise the importance of international networks for fostering innovative development (see Chapter 2). As I explained in Chapter 3, Latin American STS scholars regard international dependencies as historical channels of diffusion in the region. Yet at the same time, local material and intellectual capacities have grown enough over the years to the point of constituting key valuable and alternative diffusion channels. I consider this spatial tension central for understanding dependency relations in contemporary science.
Centre and Periphery

Lastly, I understand the notions of ‘centre and periphery’ as combination of the previous two concepts. The power dynamics of space and its functional dimension create a conceptual division of the international scientific community into ‘centre’ and ‘periphery’. The former is comprised by those countries and regions that enjoy a privileged access to research resources, whereas the latter includes those actors that have a more distant and restricted access to them. In knowledge diffusion studies, this conceptual diction also allows researchers to track the mobility of ideas and knowledge across geographical settings and understand them in framework of power differentials. In the 1990s, for instance, Thomas Schott (1991) revived Basalla’s diffusionist model and argued that scientific ideas and institutional arrangements tend to diffuse from the centre to the periphery. While nowadays it would be more appropriate to speak of ‘centre(s)’ and ‘peripher(ies)’ (i.e. the global rise of China or the growth of South-South collaborations where countries like Brazil or India adopt leading positions, have expanded both terms), I use these concepts in their singular form. That is, my goal is not to study the nuances of these relationships, but rather understanding how the power dynamics of space intervene in knowledge production and diffusion processes. Moreover, the history of zebrafish research fits clearly to the centre-periphery description. As I explain in the next chapter, in the early years of zebrafish research, expertise was available in handful of laboratories in North America and Europe. This spatial configuration also determined the institutional arrangement of the zebrafish international community and the power relationships that were formed as a result.

Altogether, these three concepts are central for my analysis of internationalisation dynamics in zebrafish science.

Mixed-method approach

To study these key concepts, I make use of quantitative and qualitative methods. In the empirical chapters of this thesis, I move back-and-forth between these two methods with the aim of complementing them and fill the analytic gaps left by one or the other.

In Chapter 5, I study the power dynamics and dependency relations present in the standardisation of zebrafish as a genetic tool. I start by conducting a qualitative review of the history of zebrafish research using documents where I focus on the
processes that led to the institutional configuration of the early international zebrafish community. In this analysis, the power dynamics of space relate to the physical distribution of resources and stock centres in this scientific community, which are crucial institutions for researchers to access standardised zebrafish embryos and adult livestock. Following this, I use SNA techniques to map the collaboration network of the first international project that secured the role of zebrafish as a powerful genetic research artefact. By studying the institutional affiliations of the researchers that took part of this project, I track the distribution of scientific expertise in the early zebrafish community and its subsequent diffusion, an aspect that is discussed superficially in existing studies of zebrafish science history. Lastly, using interviews with South American zebrafish researchers, I discuss dynamics of dependency and empowerment present in contemporary practices of resource exchange (e.g. zebrafish embryos, reagents and lab equipment), which is also a topic largely ignored in the STS literature on model organisms.

Using bibliometrics and SNA techniques, in Chapter 6, I study the power dynamics of the zebrafish global collaboration network. To study the spatial configuration of the network, I use affiliation data stored in zebrafish publications, which allow me to identify the geographical location of every research institution and visually inspect its centre-periphery structure. Following this, I examine dependency dynamics in the diffusion process of zebrafish. I use techniques from network diffusion studies to measure how exposure to distinct types of research institutes influence the adoption of zebrafish as a model organism. While the notion of space is part of the network diffusion approach (i.e. these models assume ideas and innovations spread within and across communities), the power dynamics of space are not studied directly. Therefore, to measure these dynamics, I consider the geographical location of every actor in the network that is a user of the zebrafish model. This allows me to observe the extent to which collaborations with international partners (located mostly in North America and Europe) is a factor that explains the diffusion of zebrafish among South American research institutes. However, because the concept of 'exposure' and its connection with the notion of dependency is a subject of research that is largely taken for granted in network diffusion studies, I use interviews with South American
zebrafish researchers to inquire about the meaning of exposure to networks of international collaborators in this region.

Lastly, in Chapter 7 I study the connection between international mobility and curated annotations, which is a proxy to measure access to unevenly distributed research resources and research excellence in model organism science. I first use bibliometric techniques to understand how power dynamics are present in practices of biological data curation at the zebrafish international database (ZFIN.org). These power dynamics include biases in the search of zebrafish publications including the prioritization of publications indexed in mainstream bibliometric databases and written in English. However, bibliometric analyses by themselves do not allow me to understand fully practices of contribution to cyberinfrastructures in the zebrafish community, especially in peripheral communities. Therefore, using documents and interviews with South American zebrafish researchers, I study how power dynamics and asymmetries affect contributions from the periphery to the zebrafish international database. In the final part of the chapter, I move back to conduct a bibliometric analysis of patterns of international mobility in the zebrafish community and how these mobility practices interact with researchers’ contributions to the ZFIN database in the form of curated annotations (e.g. genes, genotypes and fish lines). By reconstructing the mobility trajectories of individual zebrafish researchers, I am able to study curated annotations against the spatial (i.e. international) displacement of researchers and therefore observe how mobility flows between centre and periphery affect the visibility of researchers in the zebrafish online database.

**Software and data transparency**

**Data mining and structuring**

Bibliometric digital archives are usually structured as relational databases where the different data inputs are stored separately in tables connected to each other by tuples or keys. One can interact, extract, structure and analyse data from these databases by means of a specific language: SQL or Structured Query Language.

**Statistical analysis**

To conduct statistical analysis on the collected bibliometric data I used the language program R and the free software RStudio. The following packages have been used when conducting this analysis:
- *netdiffuseR*: a library for conducting analysis of diffusion and contagion processes on Networks.
- *igraph*: a collection of network analysis tools.
- *readr*: a package to read rectangular data in a fast and friendly way.
- *dummies*: for creating and manipulating dummy variables.
- *devtools*: a library for making package development easier.
- *broom*: for summarising and reporting key information about statistical models
- *MASS*: for statistical analyses.
- *rpart*: for building regression and survival trees.

**Visualisations**

For data and network visualisations, I used the following R packages and software:

- *ggplot2*: data visualisation package for R.
- *Gephi*: a free software for analysing and visualising network data.
- *Power BI*: a business analytics service by Microsoft. Specially used for data visualisations on scientific mobility in Chapter 7.

**Datasets and scripts**

All datasets used in this thesis, as well as the scripts used to run the analysis are provided in the ‘Supplementary Material’ file. For detailed information on this material, please refer to the list provided at the beginning of the document (‘Supplementary Material’).

**Ethics, funding and research positionality**

This project did not pose any reasonable ethics risks, regarding the invasion of personal privacy nor potential social or emotional risks. However, because the study involved interviews, I requested informed oral consent from participants. At the beginning of each conversation, besides asking them if they agreed to record the interview, I devoted some time to explain the project, the purpose of the interviews and address any questions they may have had in advance. Moreover, all of the interviews have been anonymised to protect the interviewees’ identities and the audio and transcript records have been stored in a OneDrive with restricted access.
This research has been funded by the 1+3 Economic and Social Research Council (ESRC) Award from the Scottish Graduate School of Social Sciences (Science, Technology and Innovation pathway) and a Special Award from the Graduate School of Social and Political Science of the University of Edinburgh. In addition, fieldwork research was possible thanks to financial support provided by the ESRC-SGSSS Overseas Fieldwork Expenses Fund and the Overseas Institutional Visit fund.

As I explained in the introduction, the project has evolved considerably from the initial formulation. In addition, the thesis differs considerably from both the Master’s dissertation submitted in August 2017 and the research the proposal laid out in the Board Paper in January 2018. In these two documents, I proposed to focus on a series of research institutions in Argentina and Uruguay with a strong international projection as well as to study the construction of measurement standards of scientific internationalisation in Latin America. Difficulties accessing the research institutes and the anticipation of severe methodological limitations that could result from the proposed research design informed the decision to change the scope of the study. In this sense, the case study on zebrafish research allowed me to develop a stronger focus on internationalisation dynamics and reach a large number of researchers in three South American countries.

In many ways, my own trajectory (i.e. a South American migrant, student and worker) took me to choose internationalisation as a research subject. I moved from Argentina to Spain with my family at relatively young age. In the more than 20 years that have passed since then, I have returned to Argentina, moved back to Spain and lived for short and long periods of time in The Netherlands, Ireland and Scotland. This is a testimony of my long record of experience with international mobility and a personal account of internationalisation. During my undergraduate in Political Science and later during my first Masters in International Relations I also developed an interest in topics related to cooperation and regionalisation policies that continue to these days, and which are closely related to the concept of internationalisation, as I discussed in Chapter 2. However, it was my time working with science and technology indicators in Argentina when I first came across the notion of scientific internationalisation and when I began to develop a serious interest in this topic. My time working at the RICYT also gave me a valuable first contact with scientometrics and quantitative analysis, which I was able to strengthen during the PhD programme.
I also acknowledge that altogether, this training background made me feel confident, from the beginning of the project, that I could learn complex techniques when I needed, and pursue mixed-method research even though this is a challenging choice in STS.

**Discussion**

In this chapter I presented the general research design and methods used in this thesis which takes the model organism ‘zebrafish’ as a case study of internationalisation dynamics in South American life sciences.

I began the chapter discussing how model organisms have been used as case studies for studying social dynamics of scientific research with a special focus in Latin American STS. I then described the many features that make zebrafish an interesting case to study how complex dynamics of scientific internationalisation intervene in processes of knowledge production and diffusion in contemporary life sciences. The latter include its relative economy allowing average peripheral laboratories to conduct world-class research, its unprecedented growth in South America life sciences, and the existence of cooperation networks and communal infrastructures that are thought to play a major role in the diffusion of zebrafish research and the promotion of scientific excellence worldwide.

I consider the study of scientific internationalisation as requiring insights from both quantitative and qualitative methods. Therefore, after presenting the thesis’ aims and questions, I discussed the implications, limitations and opportunities of combining methods in this particular discipline. This was followed by a detailed description of the data sources, methods and techniques that I have used in this project. In particular, I sought to introduce bibliometrics and social networks analysis to readers unfamiliar with these techniques. In the last part of the chapter, I described issues related with data transparency, ethics and research positionality.

The following chapters present the empirical research conducted on the zebrafish case as well the conclusions of the thesis.
Chapter 5: Constructing the Zebrafish as a Model Organism

Introduction

Zebrafish, a tropical freshwater fish from the Ganges region of India and popular in pet shops, has become an attractive model organism in contemporary life sciences research. The zebrafish has become famous to the extent of ‘starring’ its own documentary. Jennifer A. Manner, Director of the documentary ‘Zebrafish: Practically People, Transforming How We Study Disease’ highlighted the significance of this little fish for scientific research in these terms:

”[...]in a world where healthcare spending is out of control, zebrafish are transforming the way we study and cure disease by yielding better data, for pennies on the dollar, in a fraction of the time” (zebrafishfilm.org 2018).

Although the use of zebrafish in scientific research has been growing steadily on the world-stage, in South America its growth has been unprecedented (Buske 2012). The promise of zebrafish in this region is mainly due to the economy of the model allowing average laboratories, which often operate with small budgets and with less well-developed science infrastructures, to conduct world-class research (Allende et al. 2011, 33).

In this chapter, I will investigate how internationalisation dynamics influenced (and continue to influence) its construction as a model organism. In this sense, my goal is twofold. First, I aim to show how various internationalisation dynamics played a crucial role in the standardisation process of zebrafish as a genetic tool and in the formation of the international zebrafish community and its proclaimed research ethos. Second, by focusing on the experiences of South American researchers, I seek to unpack complex dynamics of dependency and empowerment present in practices of resource exchange as well as the barriers and reactions to international infrastructures built to support these exchanges.

Motivations for focusing on the processes intervening in the construction of zebrafish as a model organism are also twofold. On the one hand, the opportunity to study the relationship between knowledge construction processes and practices of resource exchange and on the other, addressing the literature gap regarding the
connection between internationalisation and model organism. While the STS literature on model organisms has described the moral rules and social structures that govern the construction of biological artefacts as model organisms, scholars have paid little or almost no attention to the study the role of internationalisation dynamics in these processes. Overall, the analysis developed in this chapter revisits the unproblematised collaborative ethos associated with model organisms’ communities. In particular, their description as uniform and harmonious ecosystems where researchers share resources freely and unselfishly.

I focus on two key material features of the zebrafish model. First, I describe its intricate standardisation process involving two well-defined historical construction phases: (1) constructing zebrafish as a research tool and (2) constructing zebrafish as a scaled-up genetic artefact. Second, I investigate the material infrastructures, including the social structures (i.e. practices of resource exchange), built to support the exchange of zebrafish stocks in the international zebrafish community in which South American researchers take part.

In the first case, I make use of documents (i.e. scientific papers and personal accounts by zebrafish pioneers) that help me reconstruct the history of the standardisation process of zebrafish as a model organism. In the second part, I rely on documents published by the zebrafish community describing guidelines and protocols for exchanging stocks via existing centralised international infrastructures. In addition, I use extracts from interviews with various South American zebrafish scientists to analyse and describe practices of resource exchange in peripheral contexts. In terms of units of analysis, I adopt a multi-level perspective. In some cases, this means following the research trajectories of individual scientists and observing how institutional and global processes intervene in them. In others, it requires placing the emphasis on institutional structures to understand how their international scope affects scientists’ individual experiences.

Before delving into these issues, I discuss relevant concepts developed by STS literature on model organisms with the aim of explaining readers the conceptual framework this chapter is built upon. Concretely, I discuss what we actually mean when we talk about the ‘material features’ of model organisms and how this interacts with the definition of scientific internationalisation laid out in Chapter 3.
Constructing model organisms: epistemic and material features

In recent decades, model organisms have become ubiquitous in life sciences research. They have gained what Kalueff, Echevarria and Stewart (2014) refer to as ‘translational momentum’ where human disorders are increasingly linked to animal models and biomarkers. Moreover, in the context of the HGP and the associated large genomic sequencing projects, model organisms have acquired prescriptive power. As noted by Leonelli and Ankeny (2013), due to the popularity of the term, many research groups are experiencing pressures from competitive granting systems to focus on certain organisms or to rationalise any research proposal on a particular organism by claiming that it is, in some sense, a ‘model organism’ (p. 209).

Despite its wide use, the term ‘model organism’ has distinctive epistemic and material features that distinguish it from other organisms used for experimental research purposes only. Model organisms like the *E. coli*, *Drosophila*, *C. elegans* and *Denio rerio* (zebrafish) are a specific subgroup of organisms that have been standardised to fit an integrative and comparative mode of research (Ankeny and Leonelli 2011, 319). Model organisms have two well-defined epistemic features: ‘representational scope’ and ‘representational target’. The former is an inductive presumption that derives from the principles of genetic conservation by which smaller genomes are thought to represent more compact and simpler forms of more complex and higher genomes, and are thus more appropriate for genetic studies. The latter is a consequence of the former and establishes that model organisms can represent a range of systems and processes (‘targets’) occurring in living organisms (Leonelli and Ankeny 2013).

Some scholars have questioned some of the features of model organisms such as the claim they are fair representations of other species. Jessica Bolker (1995, 451–52), for instance, notes that many organisms do not adjust to this idealised vision and argues there exist inherent biases involved in model organisms’ selection, e.g. rapid development rate and short breeding cycles. In contrast, Ankeny and Leonelli (2011) consider these ‘biases’ as part of model organisms’ material features (p. 313). In this sense, all model organisms have particular experimental features that turn them into powerful genetic tools: small physical and genomic sizes, short breeding and life cycles, high fertility rates and high susceptibility to simple techniques for
genetic manipulation. Such features are very familiar to zebrafish researchers. All of the consulted reviews on zebrafish make reference to this set of material features along with the additional advantage of the external and transparent development of embryos, which is not found in other model organisms (see Kalueff, Stewart, and Gerlai 2014; Kalueff, Echevarria, and Stewart 2014; Stewart et al. 2014; Varshney, Sood, and Burgess 2015). And in the case of South America, all the scientists interviewed for this research project agree that these canonical attributes informed their reasons for selecting this small fish as a model organism in the first place (Interviews with PI-Chile-2 2018; PI-Uruguay-1 2018; PI-Argentina-7 2018; PI-Argentina-8 2018; PI-Chile-1 2018; PI-Chile-3 2018, 3; PI-Uruguay-4 2018).

Besides being well developed as standardised research models, organisms with successful publication records tend to be used by well-organised communities with good networks of exchange and methods of communication (Dietrich, Ankeny, and Chen 2014). Consequently, large-scale comparative research constitutes a key goal of model organism research that becomes achievable by gathering and sharing resources and building infrastructures to support these exchanges and advance research. More importantly, in the life sciences, these infrastructures are thought to play a crucial role in the formation of stable scientific communities. For Leonelli and Ankeny (2015), scientific communities in the life sciences have specific ‘repertoires’ that tie them together, meaning:

“...a distinctive and shared ensemble of elements that make it practically possible for individuals to cooperate, including the norms for what counts as acceptable behaviours and practices together with the infrastructures, procedures, and resources that make it possible to implement such norms” (p.701).

Therefore, similarly to Kuhn (1962) and Knorr-Cetina (1999), Ankeny and Leonelli reject the characterisation of research communities as being focused largely on shared theories as constitutive of a discipline or field. However, for them repertoires include elements that Kuhn did not explicitly consider; namely, the social and institutional resources and infrastructures that are crucial to contemporary biology (Ankeny and Leonelli 2016, 20).

From a material point of view, model organisms are developed as a form of resource material, a laboratory artefact that contains social structures with a specific community ethos. Early Drosophila researchers, for instance, shared strong personal
bonds and championed a distinctive moral economy that favoured the free exchange of strains and techniques (see R. E. Kohler 1994). In the Arabidopsis community, researchers foster an ethos of ‘share and survive’ by which resources are openly shared to advance research (see Rhee 2004). The ethos of sharing materials, techniques, strains and data are said to be common to all model organism communities, which have become themselves models for good behaviour in science (see Ankeny and Leonelli 2011; Rosenthal and Ashburner 2002; N. C. Nelson 2013). In turn, these social structures and the infrastructures that sustain them play a crucial role in defining what counts as knowledge and thus retaining the scientific value of model organisms beyond their respective research communities.

In the spread of these custom and moral economies, two types of infrastructures are decisive in enabling cross-disciplinary communication and facilitating collaborative behaviour: physical infrastructures (e.g. stock/strain centres) and cyberinfrastructures (e.g. community databases and online platforms). With the advent of the HGP in the 1990s, granting bodies started recognising the value of model organism research by funding not only genome sequencing projects but also ‘community resources’ such as stock centres (Ankeny and Leonelli 2011, 317). Examples of these include the Caenorhabditis Genetics Center (CGC), the Nottingham Arabidopsis Stock Centre (NASC), and the Yeast Genetic Stock Center at American Type Culture Collection (ATCC) (for a detail review of these centres, see Rosenthal and Ashburner 2002). For its part, community databases have become crucial to the collection, ordering and retrieval of data gathered on model organisms and have had a major impact on how researchers conduct and communicate their research, displacing traditional communication means such as newsletters and meetings. The interaction between internationalisation dynamics and zebrafish cyberinfrastructures in shaping notions of research excellence in this community is discussed in detail in Chapter 7. In this chapter, I will concentrate on zebrafish stock centres and practices of resource exchange, which play a key role in the construction of zebrafish as a model organism.

STS studies on model organisms are undoubtedly valuable for the study of zebrafish research as they provide a clear vantage point to study the construction process of model organisms in scientific research. However, these studies tend to ‘un-problematize’ the collaborative ethos of these communities and often lack, as Anderson (2009, 239) argues for STS studies in general, a ‘critical spatial
consciousness’. Because of this, model organisms’ communities and their infrastructures are seen more as uniform and harmonious ecosystems rather than as arenas where scientific practices in geographically dispersed communities can react against or reproduce power structures derived from the social organisation of scientific practice worldwide.

Studying the role of internationalisation dynamics in the construction process of model organisms can nevertheless help to fill this gap. As explained in the previous chapter, scientific internationalisation is perceived by South American researchers working in the life sciences as a complex phenomenon that has both positive and negative connotations. On the one hand, scientific internationalisation is considered a strategic resource to conduct research in national scientific systems affected by budget restrictions, less developed infrastructures and volatile science policies. On the other hand, the internationalisation of science is often described as a relational process characterised by unequal exchanges of resources in knowledge production (including material, financial and human resources). These complex dynamics, I argue, are present in practices of resource exchange in the zebrafish community as well as in the responses coming from a ‘geographically distant community’ to the international infrastructures built to sustain the community’s social structures globally.

Before discussing this and the experiences of South American zebrafish researchers, I analyse the historical standardisation process of zebrafish that led to its consolidation as model organism on the world stage in the early 1990s. Such standardisation process can be considered a fundamental material feature of model organisms upon which the construction (and diffusion) of subsequent international infrastructures are critically dependent.

The standardisation of zebrafish

Standardisation is a characteristic of all model organisms and is said to derive from the leading role of genetics in biological research since the end of WWII. The ‘molecularisation’ of biology, as it has been described (see Burian and Thieffry 2000; Weber 2007), has defined how biologists understand two notions of central importance for developing widely representative models. First, the idea of ‘pure line’, which is crucial for experimental control and where genetic analysis acts as a defining measurement. Second, the idea of ‘comparability’ across species, which is closely
attached to the principle of genetic conservation and the representational scope of model organisms (Ankeny and Leonelli 2011, 316).

The standardisation process of zebrafish, I argue, can be divided into at least two well-defined construction stages: (1) constructing zebrafish as a research tool and (2) constructing zebrafish as a scale-up genetic artefact. In each of these stages, internationalisation dynamics including international travels, cross-border collaborations, personal networks and global historical processes paved the way for the construction of zebrafish as a standard genetic tool.

**Zebrafish as a research tool: from Ganges (India) to Oregon (U.S.) and beyond…**

The history of the use of zebrafish in life sciences research is a story of scientific internationalisation and dates back to 1822 when Francis Buchanan-Hamilton, a Scottish physician and naturalist graduated from the University of Edinburgh, first described zebrafish among fishes found in the rivers and flood plains of the Ganges region in India. Hamilton’s early description, however, did not meant to arouse any special interest for this little fish:

> In an economic point of view, the fishes of this division [*Cyprinus Danio*] are of still less value than the preceding [*Cyprinus Canius*], as they are equally insipid and smaller; nor does their number anywhere compensate for these defects (Hamilton 1822, 231).

Despite this dull description, by 1905 zebrafish was first imported to Europe as an aquarium fish and subsequently taken to the U.S. where it was first used for scientific purposes. In 1929, Hubert Goodrich began recommending fish, including the zebrafish, as a potential genetic and embryologic research model (see Holtzman et al. 2016, 1072) and a few years later, Charles Creaser (1934, 159) outlined the first techniques for using zebrafish in embryologic research. In the following decades, the use of zebrafish in scientific research involved many themes, including development, behaviour, toxicology and neurobiology; however, back then there was little organised effort behind the development of the model system (Meyers 2018, 5). Before these efforts begun to materialize in the early 1990s, the fish undertook another journey, yet this time beyond earthly geographies: in June 1976, zebrafish was sent into space by the Soviet space station, Salyut 5.
It was not until the early 1980s, however, when the use of the model made an impact thanks to its introduction as a genetic model by George Streisinger, a Hungarian-born U.S. researcher working at the Institute of Molecular Biology (IMB) of the University of Oregon. Streisinger’s research trajectory is tied to the famous ‘Phage group’, an informal network of biologists founded in the mid-20th century by what later became central figures of the history of molecular biology such as James Watson, Alfred Hershey, Salvador Luria, Max Delbrück and Sydney Brenner among others. Having trained with Luria, Delbrück and Brenner, Streisinger was at the core of the historic phage group throughout the 1950s, working at Caltech and Cold Spring Harbor in the U.S., and Cambridge University in the U.K. (Grunwald and Eisen 2002, 717).

The dropping of the atomic bombs in 1945 triggered research on phage and genetic information. The aftermath of WWII opened new pathways to secure funding and repurpose physics research (see Creager 2014; Vermeulen 2016) but also brought about a process of soul searching for many physicists who were directly or indirectly involved in the ‘Manhattan Project’. Within this context, the nature of genetic information and its encoding at a molecular level was considered one of the key problems to tackle by post-war researchers. Answering this question required a simple new biological model and many opted to study the simplest model available, phage (Varga 2018, 315).

By the mid-1960s, however, research on phage as a genetic system showed signs of exhaustion. Many considered, as Brenner anticipated to Max Perutz in 1963, that “[t]he future of molecular biology lies in the extension of research to other fields of biology, notably development and the nervous system” (Brenner, 1998 [1963], as cited in Meunier 2012, 525). This experimental turn towards brain science directed the work of many researchers – Streisinger included – into developmental biology, a subfield of biology that focuses on the study of processes involved in the embryonic development and where zebrafish research flourished in the 1980s.

Consequently, many prominent phage researchers, including Seymour Benzer and Brenner himself, decided to pioneer work in other model systems – *Drosophila* and *C elegans* respectively – to study the molecular underpinnings of brain function, which was considered the following big question once the basics of gene function and regulation were understood. However, unlike his colleagues, Streisinger considered invertebrate models of limited use in understanding and studying the
complex nervous systems and behaviour of vertebrates (Varga 2018, 317). Being a fish enthusiast, Streisinger initially brought several species of tropical fishes into his laboratory, including medaka, which had an established history of genetic experimentation.

His reasons for selecting zebrafish are not known as there are no left records of his preliminary investigations on these fishes (Grunwald and Eisen 2002). Nevertheless, Streisinger’s choice for zebrafish was perceived as a big gamble for at least three reasons. First, since the 1950s, the discovery of the double helix and the excitement around molecular biology thanks to advances in phage, geared research agendas and funding into fields other than developmental biology (Wieschaus and Nüsslein-Volhard 2016, 3). Second, before the era of gene cloning there was no understanding as to whether genetic programmes that regulate development were conserved. Moreover, the post-war funding landscape that had facilitated basic research in the life sciences and the emergence of molecular biology, rapidly started to change towards the end of the 1960s. In the U.S., the budget of the National Institutes of Health (NIH) – the main federal funder on health research – slowed considerably due to the inflation of the U.S. economy and the advent of new programmes such as ‘Medicare’ and ‘Medicaid’ that competed for congressional funding (see Boadi 2014) (see Boadi 2014). As a result, Streisinger was constantly embattled to secure federal funding for his zebrafish project (Grunwald and Eisen 2002, 19–20).

Streisinger’s past involvement in the Phage group, however, became an asset to obtain funding in this complicated context and to start his work on zebrafish. The

![Figure 11. George Streisinger’s publication record. Own production based on Scopus data.](image-url)
small size of the phage community meant that personal and intimate connections could thrive and common acquaintances could be involved in peer review and funding process. Streisinger’s funding applications to external grants from the NIH focused on zebrafish were no exception to this situation (Ibid).

At the same time, his phage training had given him experience in interdisciplinary and breakthrough research. Changing research direction was very much accepted in the phage world (Grunwald and Eisen 2002). This was the case for Streisinger during his postdoc with Delbrück at Caltech (switching unsuccessfully from phage to plants) and then as a research member of the IMB with Aaron Novick (switching from phage to zebrafish). Moreover, this ethos was accompanied by a scientific culture within the life sciences that fostered the quest for a comprehensive method that would bring together research on vertebrates and invertebrates. The idealisation of this quest came to be to be known in the research community as ‘Hershey Heaven’, after Alfred Hershey, one of the founders of the Phage group and of molecular biology. When Hershey was asked to describe his idea of scientific happiness, he replied that it would involve having “one experiment that works, and keep doing it all the time” (as cited in Creager 2001, 18). In other words, this ‘scientific ideal’ meant being able to conduct every experiment using the same tools and methods, and yet always generate new and interesting data (Zinn 2016).

The drive to develop such comprehensive experimental artefact required, nevertheless, the acceptance of long-term research strategies by research institutions that often worked with short-term funding. At the IMB, Streisinger received personal support from Aaron Novick who also called other IMB members to support his new research on zebrafish. As it can be seen in figure 1, throughout the 1970s Streisinger had a big gap in his publication record coinciding with the zebrafish research period. This delay was a consequence of his desire to ‘do something big’, namely, establishing a new vertebrate genetic model (Varga 2018). In molecular biology research at the time, achieving something ‘big’ or getting closer to ‘Hershey Heaven’ meant overcoming the ‘diploidy problem’; i.e. the possession of two different alleles of a particular gene or genes by diploid eukaryotes. In other words, to dissect biological development – in particular neural development in a vertebrate – researchers needed to propagate each mutation through male and female heterozygous partners to produce homozygous offspring for screening (i.e. having
two identical alleles of a particular gene or genes) (Streisinger et al. 1981; see also Grunwald and Eisen 2002).

Streisinger’s famous 1981 Nature paper is the culmination of the work on zebrafish he carried throughout the 1970s and his effort to develop a new vertebrate model. In it, Streisinger presented a method that allowed producing mutants in a more efficient way: using unfertilized reproduction to avoid the need to propagate mutations in both male and female partners (Streisinger et al. 1981). Streisinger’s technique, which constituted the baseline of his grant application to the National Science Foundation (NSF) eight years before, involved the use of a simple physical treatment (e.g. UV light-treated sperm and the application of hydrostatic pressure or heat shock), characteristic of classical embryology, to produce homozygous diploid zebrafish more effectively. This technique made Streisinger the first person to clone a vertebrate, but more importantly, it made the zebrafish a serious candidate for genetic analysis. Nevertheless, the transformation of the zebrafish into a novel and attractive model was a consequence of a series of international efforts that took place from the late 1980s until the mid-1990s.

**Zebrafish as a scaled-up genetic artefact: towards the ‘Big Screens’**

As anticipated in his seminal paper, Streisinger’s technique favoured the performance of large-scale screenings for mutants and facilitated genetics analyses on a vertebrate (Streisinger et al. 1981, 293). In genetics, a genetic screen is the procedure used by researchers to identify the function of an unknown gene by introducing random mutations into an organism (i.e. forward mutagenesis) and then conducting systematic visual inspections of differences in their physical characteristics or phenotypes. A mutation is thus the means to observe the disruption of specific biochemical pathways and understand the function of a gene in development, while description allows researchers to characterise the phenotypic effects of the mutations. In order to understand developmental mechanisms, screens need to be conducted on a large scale, which requires in turn the production of a large number of mutants. This constituted a major challenge in vertebrates.

Streisinger’s work took place in the context of the wider developments of researchers beginning to recognise the potential of mutagenesis to study developmental phenomena in invertebrates since the mid-1970s. In Germany, Eric Wieschaus and Christiane Nüsslein-Volhard conducted large-scale mutagenesis
screens of the *Drosophila* to gain insights into the biochemical mechanisms controlling developmental decisions. In the U.K., Sydney Brenner performed large-scale screens to study neural development and function in *C. elegans*. The work of Nüsslein-Volhard and Wieschaus, in particular, showed that collections of fly mutant phenotypes could be woven into broader contexts in order to explain the role of cellular mechanisms in development programs (Nüsslein-Volhard and Wieschaus 1980). These new insights, however, still proved elusive in vertebrate research as producing mutants on a large scale remained challenging, time-consuming and very expensive (Grunwald and Eisen 2002, 722). Seven months after Nüsslein-Volhard and Wieschaus’ published the results of their screen in *Nature*, Streisinger published his technique in the same journal confirming that mutants on a vertebrate could be produced and arguing that similar genetic approaches could be taken to study development phenomena in a vertebrate.

Once the method for producing mutants was established, the next step involved the development of techniques to induce mutations in the fish (see Chakrabarti et al. 1983; Walker and Streisinger 1983; Grunwald et al. 1988). Streisinger’s 1981 paper caught the attention and interest of other researchers from the University of Oregon such as Charles Kimmel, Monte Westerfield and Judith Eisen who were working at the Institute of Neurology. Because of their shared interests in the patterning and differentiation of the nervous system, in 1984 Streisinger and Kimmel began to plan a genetic screen in collaboration. This project was nevertheless interrupted due to Streisinger’s sudden death that same year and the subsequent reluctance of the NIH and the NSF to continue the funding because they understood the project as Streisinger’s personal quest (Grunwald and Eisen 2002, 721).

After Streisinger’s death, work at Oregon concentrated on securing the legacy of Streisinger and giving shape to an incipient zebrafish research community at a moment when other laboratories begun planning mutagenesis screens on zebrafish. An informal course on zebrafish husbandry, genetics and embryonic anatomy was organised at the University of Oregon hosting several visiting scientists and sending representatives to other labs (Ibid). Meanwhile, in an early effort to standardised and internationalise Streisinger’s work, Westerfield produced a book titled ‘*The Zebrafish Book*’ which contained a review on various methods including care, breeding and genetic manipulation techniques (Westerfield 2000).
On his part, Kimmel embarked on the design of a research programme that spanned over ten years and which helped defining the wide range of developmental questions that researchers worldwide could address with this fish. Two papers in particular reflect the crucial role of Kimmel’s work in securing a central place of zebrafish in vertebrate developmental biology research. First, in 1989 he published a review paper discussing recent findings at the time about conservation in vertebrate developmental processes. In it, he argued in favour of adopting zebrafish as model organism on the basis of its complementarity and developmental advantages – the transparency of zebrafish embryos being the most important – vis à vis other existing vertebrate models (see Kimmel 1989). Second, in 1995 Kimmel published the results of a study describing the stages of embryonic development of zebrafish that served as the basis for descriptions to be developed by future genetic studies. Kimmel’s 1995 paper facilitated descriptive work – a prerequisite to mutation based studies (Meunier 2012) – and constitutes to this day the most cited paper in the zebrafish research community (see Kimmel et al. 1995).

Overall, these efforts sought to make the University of Oregon the international reference point and a sort of ‘obligatory training passage’ for researchers of the incipient zebrafish community. In light with this ambition, the University of Oregon hosted in 1990 the first international zebrafish meeting. According to the report of the workshop, assistants gathered in Eugene to identify and discuss what was needed to get the zebrafish model up to speed. One of the central conclusions of the meeting was the need to develop technical tools to produce mutants at a large scale (Barinaga 1990, 251). Two researchers raised up to this challenge: Nüsslein-Volhard and Wolfgang Driever. Nüsslein-Volhard had visited Eugene in the late 1980s and her work on Drosophila in the late 1970s placed her as the most experienced researcher to deliver the desideratum of the 1990 meeting. For its part, Wolfgang Driever, who as a graduate student worked at Nüsslein-Volhard’s lab, had completed a postdoc with Monte Westerfield in Oregon in 1991 after which he set up his own lab at the Cardiovascular Research Centre of the Massachusetts General Hospital (MGH) in Boston (U.S.) with the support of Mark Fishman (Nüsslein-Volhard 2012). Together, these two labs conducted the very first international collaborative research on zebrafish.

As noted earlier, one of the main challenges to conduct large-scale screens was the need to breed a large number of fishes. As recalled by Nüsslein-Volhard
(Ibid), the protocols and recipes developed at Oregon, however, proved ineffective outside Eugene where water and space were cheap and fish were kept in large tanks at low density with a constant flow of fresh water. In Boston, Kimmel and Fishman developed a fish facility that included a system for filtering and recycling water, while in Tübingen, Nüsslein-Volhard’s group developed a facility to grow fishes more compactly with recycled water, streamlining their handling (Ibid, p.4100).

The participation of Tübingen and Boston groups not only meant the widening of the zebrafish community, which until then was confined to the University of Oregon, but more importantly the establishment of a new division of research labour. While the Tübingen and Boston groups would be responsible for producing large number of mutants and make them available to the research community, the University of Oregon would act as the curator of the increasing amount of data derived from these large screens and other small screens being performed by laboratories elsewhere. This division was formalised at the 1994 Cold Spring Harbor (CSH) meeting on zebrafish genetics and development funded by the NSF. At CSH, 350 individuals from over 100 labs in 16 countries participated in the first open-invitation meeting to be devoted to research on zebrafish. The meeting included a session on community organisation “to discuss common goals of the zebrafish research community and to establish means for the collection and dissemination of information and research reagents throughout the community” (NSF 1994).

Specifically, two important decisions were taken at the 1994 CSH meeting that further molded the structure of the incipient international zebrafish community. First, it was decided that the University of Oregon would serve as the centralized resource centre for the international zebrafish community by hosting and managing two crucial infrastructures: the Zebrafish International Resource Center (ZIRC) and the Zebrafish Information Network (ZFIN). The former will be discussed in detail in the next section of this chapter whereas the latter is the object of analysis of Chapter 7. Second, a consensus was reached to publish the results of the Tübingen and Boston screenings together in a special issue of the journal Development, which would be devoted entirely to zebrafish mutants. The goal was to provide researchers all the information in one issue to enhance the usefulness of the mutant collection (Nüsslein-Volhard 2012, 4101).
Development's special issue: the ‘Big Screens’

The 37 papers that made the special issue described around 1,500 mutations in more than 400 new genes affecting a wide range of developmental processes. The publication of the issue not only consolidated zebrafish as a powerful genetic tool for developmental biology research but also made the Tübingen group, and to a lesser extent the Boston group, the main producers of zebrafish mutants in the incipient research community. Between the two groups, they recovered ~4,000 embryonic lethal mutant phenotypes that were of ultimate value to the general research community: the mutants needed to be described, sorted into complementation groups and preserved to make them accessible to the research community (Grunwald and Eisen 2002, 722–23).

Figure 12. Covers of Nature (1981) and Development (1996) containing Streisinger's findings on zebrafish cloning and the results from the ‘Big Screens’ respectively.

9 Not all the papers submitted passed the peer review process and not all the mutant phenotypes made it into publications (see Nüsslein-Volhard 2012).
As a result of this editorial decision, the Tübingen and Boston screenings project – which came to be known informally as the ‘Big Screens’ – are often considered the first large-scale international zebrafish project even though the screenings and the majority of phenotypic descriptions were not conducted in collaboration. This is clearly seen in the co-authorship networks maps of the 1996 special issue. In figure 13, the separation between the two groups is easily spotted.

**Figure 13.** Co-authorship network of the zebrafish Development special issue (1996). Node colours represent the main institutional affiliation. Own preparation based on Scopus data.

Each node (circle) represents an author and the links between authors (edges) reflect a paper signed in collaboration between any pair of researchers. The thickness of the edges express the number of paper co-authored between them where the thicker the edge, the larger the number of papers co-authored by these two authors.
The size of the nodes have been adjusted by their degree centrality meaning the total number of collaborators (co-authors) each researcher had in the context of the screenings. Lastly, the colour of the nodes represent the institutional affiliation listed for each of the authors in the publications. As shown in figure 13, the network is divided into two well-defined clusters, each including researchers from the Tübingen and Boston groups. The overall network density is quite low: only 24% of all possible ties between the researchers are present reflecting the low cohesion of the Big Screens project.

**Figure 14.** Co-authorship network of the zebrafish Development special issue (1996). Node colours represent the institutional affiliation at time of publication. Own preparation based on Scopus data.
Compared to the Boston cluster, the Tübingen cluster is more densely connected and is slightly bigger as it includes international collaborations with researchers from the Imperial Cancer Research Fund, the Howard Hughes Medical Institute and the University of Oregon. The internationalisation profile of the Tübingen cluster can also be explained by the group’s decision of refusing to share mutants before the publication of the special issue and the invitation instead to join the group in the analysis of phenotypes (Nüsslein-Volhard 2012, 4101). As shown in the graph, researchers from other institutions occupy peripheral positions in the Tübingen cluster and the only researcher that connects the two clusters is Jau-Nian Chen, who was part of the group of researchers invited to Tübingen. Lastly, whereas in the Boston cluster, Wolgang Driever, and Mark Fishman to a lesser extent, occupy central positions reflecting the central role they played in the U.S. screening project, in the Tübingen cluster, central positions are more spread, although the high degree centrality of Nüsslein-Volhard is a product of her position as Principal Investigator (PI).

Despite not being a strictly international project, the Big Screens did have a decisive and immediate internationalisation effect. The uncovering of the genetic bases for the phenotypes of these lines opened a vast pool of resources for laboratories worldwide to conduct related mutagenesis screens. This was especially relevant for those postdocs and students that took part in the screenings and who began to set up their independent labs immediately after (Meyers 2018, 27). In figure 14, the colours of the nodes have been readjusted to represent the actual institutional addresses of researchers when the special issue was published in 1996. As it can been seen, a large majority of researchers who took part in the screens – most notably in the Tübingen group – either went back to their previous institutions or stated new institutional addresses in the U.S., the U.K., Germany, Israel and Switzerland.

Perhaps more importantly, the Big Screens helped to set in motion efforts to consolidate the representational scope of zebrafish and regain the attention of funding agencies in the context of the international Human Genome Project. A year after the special issue was published, the Trans-NIH Zebrafish Coordinating Committee (TZCC) was established with the aim of promoting the use of zebrafish and ensuring the efficient integration of NIH activities to provide critically needed tools for the zebrafish community (Rasooly et al. 2003, 490). Among the recommendations of the newly created TZCC, there was the need to develop genomic resources for zebrafish channelled through a series of initiatives including a workshop held in 1997, a Request
for Applications (RFA) launched in 1998 and an ongoing Programme Announcement (PA) open for U.S. and foreign research institutions. The guidelines of the NIH-PA, in this sense, recognised the crucial contribution of the Big Screens and the value of zebrafish to study issues related to human development as well as aging and disease processes such as neurodegeneration and cancer (TZCC 2001).

In sum, early zebrafish research was made possible thanks to an international journey involving first a European researcher traveling East and then an Indian fish making its way towards the other side of the Atlantic Ocean – and later even into space. These journeys and the networks that were forged as a result, played a key role in the standardisation process of zebrafish as a model organism and in determining the structure of the emerging international zebrafish community after 1996. In what follows, I focus on the experiences of South American zebrafish researchers in dealing with the international infrastructures built to enhance collaboration in the zebrafish world in a key area of scientific practice in model organism research: exchanges of livestock. Besides this single participation of Miguel Allende – a Chilean researcher working at the Massachusetts Institute of Technology (MIT) at the time –, South American researchers were not involved in the early efforts to consolidate the zebrafish as a standard scaled-up genetic tool. By analysing the different meanings that conducting zebrafish research has in this ‘peripheral’ world region, I will show how complex dynamics of internationalisation present in these infrastructures disrupt the community ethos often associated with model organism research.

**Resource exchanges in the zebrafish community**

So far I have described the standardisation process of zebrafish into a scaled up genetic tool that materialised with the culmination of first two large genetic screens conducted in Tübingen and Boston in the early 1990s. During this time, the incipient zebrafish community also started giving shape to what constitutes the second material feature of any model organism research: the distinct infrastructures built to promote research on a particular model, facilitate collaboration among researchers and embody the community ethos associated with model organism work (Ankeny and Leonelli 2011). By focusing on the experiences of South American zebrafish researchers, I will show how complex dynamics of scientific internationalisation problematize the community ethos of the zebrafish community and disrupt the notion of model organism communities as uniform and harmonious ecosystems where
researchers share resources freely and unselfishly. To do so, I will focus on the Zebrafish International Resource Center (ZIRC) that along with the Zebrafish Information Network (ZFIN) (discussed in Chapter 7) plays a key role in maintaining the scientific value of zebrafish as a model organism worldwide.

**A note on the zebrafish research ethos**

The community ethos defines the boundaries of what it means to conduct research on model organisms and what it takes to be considered an active participant in the scientific community. In the early *Drosophili*st community, for instance, the exchange of standard stocks and practices helped to integrate geographically dispersed practitioners into a working community while boosting scientific production on this model. The standardisation process of the fly further helped establishing a distinct moral economy, that regarded engaging in free exchange as a mark of professional identity (R. E. Kohler 1994, 133). At first sight, in the zebrafish world too this ethos of exchange and collaboration is considered a distinctive feature of zebrafish research practices spreading across geographies. Notice, for instance, how a South American researcher describes the zebrafish community when asked to explain the benefits of working with this fish:

> It is a fact for people working with this model that in the international zebrafish community there is a policy of open doors and of sharing resources. We depend a lot on transgenic strains and available mutants and the exchange of this is quite simple. [...] Here there is a thing that has worked quite well which is the generosity of the community. [...] That generates a feeling that you can count on your peers to help you and this is a clear advantage (PI-Chile-2 2018).

Therefore, geographically dispersed zebrafish communities are critically dependent on the exchange of resources. It follows that in trying to enhance collaboration and to cope with the increasing amount of new data produced every year, members of these communities build and maintain infrastructures to support and facilitate the exchange of stocks and genetic-genomic information. So far, however, the STS literature on model organisms has limited itself to describe practices of resource exchange in model organism research as inherently collaborative and harmonious. In turn, I argue that in order to understand the performative nature of these infrastructures, it is crucial to problematize the community ethos of the zebrafish community and ask: how do researchers get access
to fish stocks? How do geographically dispersed researchers exchange stocks and expertise? How is credit assigned in these exchanges?

In South America, where zebrafish research has experienced a notable growth, lack of access to formal channels of exchange turns the property of fish lines into a key resource to position oneself strategically within national scientific systems. Yet at the same time, national and international obstacles to the exchange of zebrafish stocks have brought about regional and informal channels of exchange that allow South American scientists to conduct world-class research and develop research niches. In what follows, I analyse practices of resource acquisition and exchange in both formal and informal channels.

**Formal stock acquisition and exchanges: the ZIRC**

After Streisinger's *Nature* paper was published, various small-scale mutant screens started being performed in many laboratories resulting in a rapid increase of zebrafish mutant lines (see Jarret and McCluskey 2019). Before the creation of the ZIRC, however, genetic stocks were distributed among more than 100 laboratories in 28 countries, which often had to discontinue some of their current stocks – many of which could be permanently lost – to make room for new mutants (Westerfield 1998). Moreover, when the Tübingen and Boston large-scale screenings were completed in 1996, about 1,500 new mutations in more than 400 genes were identified increasing the total number of available mutations to over 7,000.

Consequently, at the 1994 CSH meeting, ZIRC was envisioned as a centralised facility based at the University of Oregon to maintain wild type and mutant stocks of zebrafish and to make these stocks widely available to the international research community (Driever 1996). The initial grant to construct the centre was awarded by the NIH in 1998 with additional supports from the State of Oregon to facilitate the provision of animals at a lower cost than individual laboratories and ensuring the highest possible levels of quality and uniformity (Westerfield 1998). This gives account of the public interest to secure the role of the University of Oregon as the international centre of zebrafish research in a context shaped by the HGP and the associated large-screening projects.

In model organism research, selecting which stocks to keep is a matter of judgement (Rosenthal and Ashburner 2002). In the zebrafish community particularly, both ZIRC and the University of Oregon have acquired an authoritative voice in
defining what counts as relevant future zebrafish research and in delineating the material conditions laboratories must comply with to access the model. According to guidelines established at ZIRC, submissions of both wild type and mutant strains are subject to an evaluation process on behalf of the ZIRC staff based at Oregon and an External Review Board composed of three or more scientists with extensive and varied expertise in many areas of biomedical research. In this process, the criteria for strain approval includes an assessment of (1) the line relevance for current or anticipated future research, (2) the availability of information about submitted lines, (3) the availability of genotypic/phenotypic identification procedures, and (4) the submitter capacity to maintain a strain(s) until it is fully established in the stock centre (ZIRC 1997).

In addition, line submissions to ZIRC must comply with a series of requirements such as the provision of adult fish (for submission of 50 lines or fewer) or frozen sperm (for submission of more than 50 lines). Sending stocks is also well regulated. Embryos are typically sent by ZIRC staff early in the week to avoid travel during a weekend and recipients are expected to take care of customs arrangements in advance, which can be quite restrictive. Recipients are also required to be ready to care for the fish (either embryos or adults) before they are shipped and this demands the establishment of adequate fish facilities and the application of specific husbandry procedures as detailed in the Zebrafish Book (ZIRC 1997). In any case, ZIRC does not accept submissions in the form of embryos, which are nevertheless the preferred form for shipping stock to laboratories around the world given its simpler shipping procedure and lower costs.

The centralised exchange of zebrafish stock is not exempt from complications. Sending fish across borders poses serious logistical and administrative burdens to laboratories worldwide. By the early 2010s this led to the establishment of regional stock centres in Europe and China heavily funded by governmental bodies (Varshney, Sood, and Burgess 2015, 10; Strähle et al. 2012, 92; Xie, Pan, and Sun 2015, 398). To promote zebrafish research in Europe, the network EuFishBioMed was formed in 2007 and funded by the COST programme, a EU-funded, intergovernmental framework for the creation of European research networks (COST 2019). The EuFishBioMed network established the biannual European Zebrafish Principal Investigator Meetings (EZPM) and successfully lobbied for the construction of the European Zebrafish Resource Centre (EZRC) located at the Karlsruhe Institute of
Technology in Germany. Opened in 2012, EZRC contains several thousand mutations from the laboratory of Nüsslein-Volhard and from the Sanger Mutagenesis Project (Geisler 2013). While the EZPM provides an exchange platform for researchers with a stronger focus on European issues (Brennan et al. 2010, 305), the EZRC acts as the permanent repository for zebrafish lines from European researchers (Strähle et al. 2012).

In the case of China, zebrafish research started later than in the U.S. and Europe although in the last 15 years the Chinese zebrafish community has been one of the most rapid growing communities in the world (see Ma et al. 2016). Due to a growing internal demand, the Chinese zebrafish community established similar institutions to its European and U.S. counterparts: the National Zebrafish Research Conference of China (NZRC), the Chinese Zebrafish Principle Investigator Meeting (CZPM) and the China Zebrafish Resource Centre (CZRC) located in Wuhan are key examples. The CZRC is jointly supported by the National Basic Research Program from the Ministry of Science and Technology of China and the Key Research Program of the Chinese Academy of Sciences (Xie, Pan, and Sun 2015; Liyue et al. 2016).

Regional networks and informal stock exchanges in South America

In South America, the formation of a regional stock centre, as those existing in the U.S., Europe and China was considered out of reach for this region given the budgetary efforts this would have required. Instead, in December 2010 a group of Principal Investigators from Argentina, Brazil, Chile and Uruguay, who were part of the Latin American Society of Developmental Biology, decided to create the Latin American Zebrafish Network (LAZEN) with the aim of "enabling resource sharing, starting collaborative research, identify funding opportunities and to enhance training" (Allende et al. 2011, 31). The regional network was initially funded by a grant from the Amsud-Pasteur Foundation, a bilateral cooperation instrument between the Uruguayan Public Health Ministry and the French Pasteur Institute to support thematic networks (interview with PI-Uruguay-4 2018). Subsequent funding for the network’s biannual meetings came from various international sources including the International Centre for Genetic Engineering and Biotechnology (ICGEB), the United Nations University BIOLAC and the Millennium Science Initiative (Whitlock 2014; David et al. 2019).
One of the central discussions of these regional meetings, which later included research groups from Colombia, Ecuador, Mexico and Peru, revolved around how to disseminate and standardise regional zebrafish work. This was deemed crucial for a series of factors: (1) countries in the region are characterised by a lack of access to centralised commercial holding systems, (2) most laboratories have homemade systems and (3) many researchers are self-taught in the art of fish husbandry (Allende et al. 2011, 33). As confirmed by several zebrafish researchers interviewed for this project, these issues pose critical challenges to conduct research locally, as fish stocks imports are subject to rigorous and non-standardised national customs restrictions. To bypass these barriers, many South American zebrafish scientists access fish stocks via local pet shops and aquariums or via informal channels. As one Argentine researcher explained:

[The importation of mutant lines] is a terrible issue and there is no way it can be solved. It has been years – years! – since we have been working with local authorities to generate a channel to import fishes. Our collaborators happily send us the specimens, but the key problem is that the fishes die if you do not extract them in a reasonable period. Of course, they are shipped in special packages but after 48hs, they asphyxiate. It is not like the mouse or the rat that you can feed constantly. There is no way to solve this! […] I have said it to the Minister, the Agency Director and to the Research Council’s President: ‘all of our fish lines are smuggled. We have brought them hidden in our clothes and in our luggage when some of us travelled abroad. It was the only way to have the lines that we currently have’ (PI-Argentina-9 2018 my emphasis).

In South America, researchers recognise the collaborative ethos of the international zebrafish community and often consider national restrictions as the major impediment to access fish stocks. Therefore, international mobility and personal contacts constitute key resources for researchers in the region to access not only fish strains but also techniques, equipment and the necessary expertise to develop zebrafish research. As described by a Uruguayan researcher:

When we started tuning up the zebrafish model here, we established a very productive collaboration with Dr X in England, which is one of the persons I knew from my time in the U.S. I mean, I had a contact, a previous knowledge of that person yet the collaboration format was different: back then, we sent someone from our laboratory to train with the model and then we brought all the know-how here to set up the model (PI-Uruguay-1 2018).
Access to zebrafish embryos via either formal or informal channels demands, nevertheless, expensive facilities to raise them successfully. Principal Investigators 7 and 8 share a laboratory in Argentina but work on different themes. They learned to take care of fishes – usually acquired from local aquariums – gradually and in a handcraft manner, they explain. Both have read the ZFIN manuals on fish husbandry protocols but they had to adapt these standard guidelines to their context and possibilities. Zebrafish facilities for keeping and raising transgenic lines are very expensive, they argue, and require full time technicians exclusively devoted to taking care of the fishes. However, these resources are not easy to obtain from public funding bodies (fieldwork notes 2018).

Moreover, because transgenic lines are usually shipped as embryos, having proper facilities installed therefore becomes a *sine qua non* condition to access fish stocks via either formal channels (e.g. ZIRC) or informal regional networks (e.g. LAZEN). In a joint conversation with PI 7 and 8, this was highlighted clearly:

PI-8: I was invited to one of the LAZEN meetings. There they offered us transgenic fishes although they were not useful to us – if they do not have tagged cells […] they are not good for us. But then, *they told us that if we did not have a tuned up facility, they would prefer not to give them to us*. I don’t know why. They are tiny eggs. They cost nothing.

PI-7: What they want is that you raise them and you then include them in the paper. You know, if they give you the knock out, you *have to include them*.

P-8: Sure (PI-Argentina-7 and PI-Argentina-8 2018 my emphasis).

The above conversation also raises questions about the assignation of credit in informal exchanges and the meaning possessing transgenic lines acquires in Latin American contexts. As seen in Chapter 3, expertise-based collaborations involving the exchange of research resources often implies the inclusion of international partners as co-authors in publications where the research questions – and often the research tasks too – have not been conducted in collaboration. Moreover, both parties recognise this convention, which involves more than just an exchange of stocks. For instance, when asked about their motives for welcoming researchers from South America, a European zebrafish researcher I interviewed confirmed that the main reason is getting publications hopefully. Moreover, they argue that there exists a key difference between research visits from Europe and abroad. European visitors can
stay for a week and learn a specific technique, which does not demand a lot of work on behalf of the hosting lab’s staff. However, international visits, they argue, have to stay long enough; a few months at least, to learn the technique and do the project themselves. In this case, however, the exchange formalises in a publication prior the validation of the head of laboratory (interview with PI-Netherlands-1 2018).

Figure 15. Self-made zebrafish tanks in a Latin American laboratory (left) and standard zebrafish rack tank (right) (Fieldwork 2018). The fishes in the left picture were purchased from a local aquarium. These facilities are not appropriate for raising embryos for which fish tanks (e.g. racks) are needed but which can cost up to 20-30.000 USD.

Therefore, international mobility constitutes a key practice for South American zebrafish researchers to access not only the model itself but also the knowledge and expertise that surrounds it. Thanks to these travels, researchers establish informal collaborations that are nevertheless formally accredited in the form of joint publications and which upon their return translate into strategic resources that help them to circumvent the challenges of conducting research in less well-equipped and volatile national scientific systems.

Additionally, having fish strains, fish facilities or acquiring novel techniques becomes a valuable asset for South American scientists to position themselves strategically within national scientific systems and to boost their scientific production. A Chilean researcher explains this clearly:

Because we are not so many [in South America], there is a sort of novelty aspect. When someone installs a zebrafish lab in a university for the first time, he or she will probably be the only one and this model allows answering specific questions that other researchers might have. […] Therefore, it is very convenient from the point of view of collaborations because with this tool you
can easily do an experiment and be included in a paper. Many people realise this and install it because it transforms into a sort of resource. [...] If you look at my publications, 60% are collaborations and probably in at least half of them, I am in the middle simply because I borrowed the model. It is a super good tool because it keeps you alive at times when you are waiting for your research lines to develop and be able to publish. This is one biggest advantages of the model in terms of Latin America where there are not many funds, we have to compete for them, publish fast and so on (PI-Chile-2 2018 my emphasis).

Other South American zebrafish scientists interviewed for this project described similar strategic behaviours that explain the choice for this model beyond its technical capabilities. Such capitalisation, as noted previously, involved the establishment of fish facilities to raise and maintain zebrafish lines. Once established, these research groups were able to engage in fruitful local collaborations and provide technology services such as toxicology tests, aquaculture research and compound screening to the community outside academia that further justifies the social relevance of their research tool (interviews with PI-Chile-1 2018; PI-Uruguay-4 2018; PI-Argentina-9 2018; PI-Chile-2 2018).

In this sense, one of the early difficulties identified at the LAZEN regional meetings was that many of the fishes used by South American laboratories were of mixed or unknown genetic background, which prompts the need for distributing standardised wild-type strains within this network (Allende et al. 2011, 33). Regional exchanges were therefore considered the means to propagate the use of standardised zebrafish stocks. However, both local and regional exchanges of stocks were not exempt from conflict. As noted by one of the interviewees, it is common that some researchers in possession of zebrafish lines refuse to share stocks or are only willing to provide adult male fishes out of fear for other researchers potentially stealing their lines (PI-Argentina-8 2018). This illustrates the extent to which exchanges through collaborative networks could at times be at odds with the stated community ethos.

Access to zebrafish stock via local aquariums or informal channels, in any case, allow researchers to conduct and publish their research as journal reviewers do not ask about the precedence of fishes, nor whether their genetic names have been previously approved by Nomenclature Committees (Ekker et al. 2015; interview with PI-Argentina-7 and PI-Argentina-8 2018). Thanks to this and the relative economy of the model vis-à-vis other model organisms, South American scientists that do not own
standardised fish lines nor have sophisticated zebrafish facilities installed (see figure 15), are able to avoid local restrictions, develop research niches and make research contributions to the international zebrafish community. One researcher, who switched from rats and purchases fishes from local pet shops, explains the possibilities offered by this little fish:

I realised that there were only two laboratories in the world working with [names substance] and fishes. In South America, this is a respite because it means you do not have to run. It happened to me when I was working in the U.S. that my boss came and told me to stop everything because he was reviewing a paper where they were doing the stuff that I wanted to do. And then, when I didn’t get funding, it was even better because the difference in value between fishes and [names another model organism] is abysmal. [...] Nowadays, I’m happy to have stayed with zebrafish because I’m doing affordable science and I am publishing in journals with a higher impact factor than when I published with rats (PI-Argentina-7 2018 my emphasis).

Overall, as geographically dispersed research groups are critically dependent on the exchange of stocks, the zebrafish transforms into a key resource for researchers to position themselves strategically within national scientific systems that have restricted access to centralised commercial holdings. Informal and regional exchange networks have emerged to cope with this situation and exchanges taking place through these channels often involve not only life stocks but also the knowledge and expertise that surrounds the model. Furthermore, these informal exchanges are often credited in joint publications allowing those who own fish lines, facilities or equipment to boost their scientific production. Yet at the same time, researchers using this model are able to conduct world-class science and develop research niches despite having restricted access to standard stocks and working with smaller budgets and less well-equipped scientific infrastructures. Taken together, these exchange practices and the internationalisation dynamics that make it possible, disrupt the perception of model organism communities as uniform and harmonious ecosystems where researchers share resources freely and unselfishly.

Discussion

Using the zebrafish as a case study, in this chapter, I have analysed relationship between knowledge construction processes and practices of scientific internationalisation. Although the use of zebrafish in the life sciences has been
growing steadily on the world-stage, in South America this growth has been unprecedented. Zebrafish and the material features that sustain its scientific value, including its community ethos, embody complex dynamics of asymmetry and empowerment. These dynamics are the product of local and global dynamics reflecting the structures of the life sciences' international scientific community in which South American zebrafish researchers take part.

In the first part, I discussed in detail the history of the standardisation process of zebrafish. In particular, I described how various internationalisation dynamics including personal networks, cross-border collaborations and global historical processes played a crucial role in the standardisation of this little freshwater fish as a research model. These developments, I explained, not only helped shaping and determining the structure of the emerging international zebrafish community at the time, but they also contributed significantly to configure its proclaimed research ethos.

In the second part, I set out to unpack complex dynamics of dependency and empowerment present in practices of resource exchange, as well as the barriers and reactions to international communal infrastructures built to support these exchanges. The ZIRC – the international zebrafish community resource infrastructure – distributes zebrafish strains to researchers worldwide at an affordable price and ensures fish lines are not discontinued. However, lack of access to centralised commercial holdings, restrictions to the imports of fishes and smaller budgets to breed embryos successfully, have made the access to zebrafish stocks more difficult and has led many researchers in the periphery to resort to informal networks, which that often extend across borders, to access the model. This has transformed the zebrafish into a strategic resource for South American researchers to position themselves strategically and boost their scientific production. Yet at the same time, even for those who are not able to own fish lines or install sophisticated zebrafish facilities, access to the model through informal channels allows them to avoid local restrictions, develop research niches and make research contributions to the international zebrafish community.

Overall, by focusing on the experiences of South American zebrafish scientists, I demonstrated how the notion of model organisms’ communities as uniform, borderless, and harmonious ecosystems, commonly found in the STS literature, becomes disrupted. The collaborative ethos often associated with these communities, I argued, is a reflection of the influence of the dominant discourse of
internationalisation. Therefore, studying practices of resource exchange among geographically dispersed communities in model organism science from the lenses of scientific internationalisation means that we regard these practices not as genuinely altruistic, but rather as reproductions of the power structures derived from the social organisation of scientific labour worldwide.

In the next chapter, I analyse internationalisation dynamics present in the diffusion process of zebrafish after the consolidation of the material features of this novel model organism in 1996, when the results of the Big Screens were published in a special issue of the journal *Development*. Particularly, I study the role of geographical collaborative networks in the diffusion of zebrafish as a model organism in South America and in other scientific regions from 1996 onwards.
Chapter 6: Collaboration Networks and the Diffusion of Zebrafish

Introduction

Sixteen years after the publication of the Big Screens’ results in the journal Development, Christiane Nüsslein-Volhard (2012) reflected on the importance of the special issue for the diffusion of zebrafish in biomedical research in these terms:

“Up to this day, the mutants [resulting from the screenings] provide a rich resource for many laboratories, and the issue significantly augmented the importance of zebrafish as vertebrate model organism for the study of embryogenesis, neuronal networks, regeneration and disease” (p.4099)

Indeed, the Big Screens turned the zebrafish into a serious candidate for genetic analysis and opened a vast pool of resources for future zebrafish researchers across the world. In South America in particular, the growth of zebrafish research since then has been unprecedented demonstrating how average laboratories, which operate with constrained budgets and with less well-developed science infrastructures, can conduct world-class research using this affordable and sophisticated model (Allende et al. 2011, 33; Buske 2012). These collaborative linkages are thought to have played a major role in the subsequent diffusion of zebrafish as a model organism worldwide and as such, they are the focus of this chapter.

In the previous chapter, I examined the case of research on zebrafish as one where we can study how dynamics of scientific internationalisation intervene in processes of knowledge production in the life sciences. I presented evidence on how these complex dynamics shape the material features that sustain the scientific value of zebrafish as a model organism in this research community and at the global stage. In addition, by focusing on the experiences of South American scientists, I showed how practices of resource exchange in collaborative networks embody dynamics of asymmetry and empowerment that challenge the vision of model organisms’ communities as uniform, borderless, and harmonious ecosystems.

The growth of zebrafish research worldwide since 1996 is framed under the widespread rise of collaboration networks in contemporary science. Collaborative networks are a distinct feature of the so-called ‘new regimes of knowledge production’
(e.g. Mode 2, the Triple Helix or the National Systems of Innovation) and one of the main drivers of knowledge diffusion across disciplinary and geographical borders (Leydesdorff and Wagner 2008; Gibbons et al. 1994). In particular, these dynamics have strongly shaped model organism research. Collaborative networks based on the exchange of resources, including species and breeding techniques, are a key pillar of the research ethos that surrounds model organism research and are regarded as its most celebrated and distinctive feature (Ankeny and Leonelli 2011).

However, scholars have also noted how the growth of collaborative research has not translated into a more equitable distribution of scientific competence, but rather to its concentration (Gibbons 1994; Olechnicka, Płoszaj, and Celińska-Janowicz 2018; Wagner and Leydesdorff 2005). The persistence of power structures in the global scientific network has prompted the renewal of centre-periphery explanations to account for the uneven diffusion of knowledge and expertise across geographies (see Wagner and Leydesdorff 2005; Leydesdorff and Wagner 2008; Glänzel, Schubert, and Czerwon 1999). More recently, this has led to new discussions revolving around the persistence of dependency dynamics in contemporary knowledge diffusion processes, which have confronted models emphasising the relevance of global pipelines to access novel ideas with those stressing the importance of local networks in fostering innovative development in science.

In this chapter, I study the role that geographical collaboration networks played in the diffusion of zebrafish as a model organism in Latin America and in other scientific regions from 1996 onwards. Bearing in mind the aforementioned collaborative scenario, I look at the extent to which the adoption of zebrafish as a model organism is explained by exposure to different spatial networks of scientific collaboration (i.e. international, regional and national). My goal is to analyse whether access to networks of experienced users of the model, presumably located outside the local milieu, explains the diffusion of the zebrafish in a peripheral regional community such as Latin America.

The notion of exposure is a central feature among competing approaches in diffusion studies, albeit differing in the implications that such phenomenon has for scientific objects. On the one hand, diffusionist approaches assume knowledge diffuses in a linear fashion which in turn allows identifying the places where original ideas are conceived. Circulationist perspectives, on the other hand, see knowledge diffusion processes as a multidirectional phenomenon as a result of which co-
production and interdependence are highlighted (see Chapter 2). Two aspects that these approaches share in common, nevertheless, is their increasing focus on social networks and their inclination to examine power dynamics surrounding space. The former results from a more dynamic conceptualisation of exposure where the emphasis on connections has successfully overcome diffusionist explanations based on the human capital paradigm. The latter is motivated by the persistence of hierarchical power structures in the global scientific network mentioned earlier, and by conceptual tensions taking place in Latin American STS, which have given rise to a distinctive form of anticolonial analysis based on centre-periphery explanations. In this chapter, I revisit this diffusion debate and argue that these conceptual developments have ultimately led to a new diffusionist hypothesis that pays greater attention to the role of social networks and the power dynamics of space.

To analyse diffusion dynamics in zebrafish research, I relied on the concept of ‘network exposure’, common in network diffusion models. I use network exposure as a proxy to measure the presence of actors with previous experience in the use of this model in the collaboration networks of research institutes. In addition, I present a methodology I developed to classify the geographical precedence of collaborators and model the influence of different spatial networks in the adoption of zebrafish as a model organism in Latin America and other regional communities. At the same time, based on extracts from interviews with South American zebrafish researchers, I take a closer look at the meaning of exposure in collaborative networks with the aim of critically reflecting of the power dynamics present in this diffusion process.

My analysis of co-authorship networks at the institutional level expanding over the period 1996-2016 shows that geographical networks are a key feature of global zebrafish research. When modelling the influence of these networks in the diffusion of zebrafish, I found that adoption behaviour among research centres is explained by exposure to a combination of national and international collaboration networks. Moreover, in peripheral communities such as Latin America, where the pace of diffusion has been slower, the effects of national network exposure are accompanied by exposure to a relatively higher share of experienced international collaborators compared to core communities in North America and Europe. However, results discard the existence of a clear pattern of international dependency in this process explained by a geographical concentration of scientific expertise in the zebrafish collaboration network. A close inspection of the nature of collaborative linkages from
the perspective of South American zebrafish researchers further revealed that exposure to networks of international collaborators has less to do with exposure to novel ideas and more with access to privileged material infrastructures resulting from the social organisation of scientific labour worldwide. Consequently, I argue that in the diffusion of zebrafish in South America, international collaboration constitutes a practice of approximation to more advantageous material structures, not concentrated knowledge.

The chapter is organised as follows. In the first section, I bring back some insights of the theoretical debate on internationalisation and knowledge diffusion discussed earlier in Chapter 2. I argue that the notion of ‘exposure’ is a common feature – albeit subject to different interpretations – among competing approaches in diffusion studies, which recently has turned the focus on the role of networks and the influence of centre-periphery dynamics. In the second section, I describe the methodology based on network diffusion models developed to study the influence of geographical collaborative networks in the adoption and diffusion of zebrafish as model organism. In the third section, I present the results of the Social Network Analysis (SNA) and the diffusion analysis based on bibliometric data. In section four, I discuss the meaning of exposure in collaborative networks for South American researchers using extracts from semi-structured interviews. In the fifth and last section of the chapter, I present a summary of the chapter’s conclusions.

Re-thinking the diffusion debate: conceptual tensions in the periphery

A linear conception of knowledge production entails the idea that the fabrication of scientific knowledge comes before its diffusion. In his classical diffusionist model, for instance, George Basalla (1967) showed no interest in studying the mechanisms behind the construction of knowledge and focused instead on studying how novel scientific ideas travel elsewhere from the place where they were originally conceived. Later reactions to the diffusionist model brought new and interesting discussions in STS that expanded the conversation on the travels of ideas by stressing the existence of power structures and/or describing the circulationist nature of knowledge rather than its linearity. Throughout this debate, the fundamental notion of ‘exposure’ of the diffusionist hypothesis has persisted albeit with a greater emphasis on social networks on both sides of the theoretical spectrum. In this section, I revisit the diffusion debate
and I discuss conceptual tensions in Latin American STS, which in my view have ultimately brought about a new hypothesis in diffusion studies.

As explained in Chapter 2, Basalla’s diffusionist model provided a linear framework for studying the creation of scientific communities and the diffusion of knowledge from a centre to the periphery (1967, 611). Basalla did not consider locality – and by extension the power dynamics surrounding space – a significant factor in the conceptual development of science and emphasised instead the international nature of scientific inquiry. In this sense, one of the most critical reactions against the diffusionist model came from postcolonial approaches, who called for the replacement of centre-periphery models with a new sensitivity towards ‘locality’, ‘contact zones’ and patterns of ‘mutual interdependence’ (Anderson and Adams 2008). By relying on these concepts, the postcolonial sensitivity therefore entailed a recognition of the reciprocal character of the circulation of knowledge as opposed to its linear conceptualisation.

In essence, the postcolonial response argues against the human capital paradigm upon which the diffusionist hypothesis was based and stresses that ‘exposure’ is synonymous with the social interactions taking place in the spaces of exchange. This in turn provided a more dynamic understanding of how scientific objects diffuse. Nevertheless, scholars like Galison (1997) or Anderson (2009), who draw on postcolonial anthropology to explain interactions in knowledge production, said little about the terms in which the exchanges between different scientific subcultures took place. In other words, while reciprocal interactions became the focus of postcolonial research, the power structures of the contact zones remained unexamined.

More recently, the growth of collaborative science and the persistence of hierarchical power structures in the global scientific network has prompted the renewal of centre-periphery explanations to account for the uneven diffusion of knowledge and expertise across geographies (Gibbons 1994; Olechnicka, Ploszaj, and Celińska-Janowicz 2018). In science and network studies, for instance, Wagner and Leydesdorff (2005) use the concept of ‘preferential attachment’ – i.e. the tendency of actors in a network to connect with more established, connected and better-known actors (Barabási and Albert 1999; Barabási 2015) – to explain the formation international collaboration networks. In these networks, they argued, researchers seek visibility, reputation, complementary capacities, and/or access to resources.
In the literature on knowledge diffusion, this has led to a debate between models emphasising the importance of local buzz – direct interactions within local settings – and those stressing the importance of global pipelines – communication with contacts located outside the local milieu – for fostering innovative development (see Storper and Venables 2004; Bathelt, Malmberg, and Maskell 2004; De Noni, Ganzaroli, and Orsi 2017; Torre and Rallet 2005; Olechnicka, Ploszaj, and Celińska-Janowicz 2018, 130). What these developments show is that in diffusionist models based on centre-periphery explanations, scholars begun paying attention to the study of social networks, which in turn transformed the conception of ‘exposure’ from a passive and linear phenomenon into a more dynamic and complex process.

Meanwhile in Latin America, scholars largely adopted a critical perspective on scientific internationalisation (see Chapter 2). On the one hand, building on earlier critiques developed by dependency and world-system theories against diffusionist models of modernisation and development (Prebisch 1950; Wallerstein 1974; Schott 1991), some Latin American scholars noted how various key dimensions of national scientific systems – e.g. the training of young researchers, the evaluation of research outputs as well as the design of research agendas and science policies – were often determined by the cognitive, financial and material resources of the richest countries and international organisations (see Vessuri 1994b; Vessuri, Guédon, and Cetto 2013; Velho 1996; Gama and Velho 2005; Kreimer and Zabala 2006; Kreimer and Meyer 2008; Kreimer and Levin 2011). In these knowledge flows, they argued, social connections and networks play a key role in maintaining historical dynamics of international dependency. However, while adopting a critical stance against scientific internationalisation, these scholars have maintained, to some extent, the linear character of diffusion as well as the passive notion of exposure; in this case, to foreign material and cognitive resources.

On the other hand, for Latin American postcolonial scholars the imperative to denounce these international power structures triggered an intellectual conundrum within this stream of thought. For this group of scholars, the rejection of the diffusionist hypothesis and the focus on the coproduction of knowledge run in parallel with a need to continue highlighting the persistence of hierarchical and asymmetrical relationships (Dussel 1995; Mignolo 2000; Santos 2008). In other words, the reciprocal character of knowledge diffusion was apparently at odds with the linear conceptions of centre and periphery, which nevertheless constitutes an undeniable reality for these
scholars. As noted by Harding (2016), this has ultimately led to a new and distinctive form of anticolonial analysis where, in order to denounce these power structures, Latin American decolonialists scholars have to continue using the very same conceptual binaries they criticise: centre/periphery, modern/pre-modern, developed/developing, and so on.

Overall, I argue that in diffusion research the notion of exposure constitutes a key feature among competing approaches, which have increasingly turned their attention towards social networks. For instance, despite being concerned with explaining the fabrication process of scientific knowledge, the postcolonial concepts of ‘interdependence’ or ‘contact zones’ keep at its core – perhaps without explicitly acknowledging – the notion of ‘exposure’ of the classical diffusionist hypothesis. Irrespective of whether invention/diffusion involve an interaction between the local and the external and/or the transformation of scientific objects, exposure to others was made possible thanks to the existence of contacts zones, the mobility of researchers and the growth of collaborative research. In some cases, such exposure entailed a clear imperial and asymmetrical exchange yet in others, where domination and conquest are less obvious (e.g. Galison’s case study: particle physics), exposure might be regarded as rather borderless and free from conflict (Galison 1997). In any case, the lessons to be taken from the Latin American postcolonial debate show that the power dynamics of space cannot (and should not) be ignored in diffusion research.

In light of this, I consider that the interactions (to use a familiar description) between diffusionist and postcolonial approaches and the resulting conceptual tensions in Latin American STS, have led to a new diffusionist hypothesis that places the focus on both the power dimensions of space and the role of social networks. In particular, I propose the following hypothesis: Scientific knowledge diffuses progressively across space through a series of networks thus exposing and bringing together an increasingly wider number of spatially distant actors.

This hypothesis can be applied to study the diffusion of the zebrafish as a model organism since 1996, when it became clear that this little fish was a serious candidate for large-scale genetic analysis. However, it should be noted that I do not seek to study whether and how the zebrafish model has been transformed as a result of these interactions, but rather how distinct spatial collaborative networks intervene in a global scientific network where knowledge is presumably geographically concentrated. To some extent, this means revisiting a sort of updated version of the
diffusionist hypothesis yet ignoring – the attentive reader would note – the nature of
the social interactions taking place in the spaces of knowledge exchange. Considering
this, besides empirically studying the influence of geographically bounded networks,
I propose to closely examine the meaning of exposure from a critical perspective to
better understand the power dynamics surrounding collaborative networks.

A methodology to study diffusion through spatial
collaborative networks

Diffusion of Innovations Theory

As noted previously, in the contemporary diffusion debate a central concept across
competing approaches is that of ‘exposure’, meaning a sort of contact or
approximation to novel knowledge, techniques or innovative practices. Recently, the
circulationist perspective has gained ground in diffusion studies and has increasingly
associated this concept with social interactions and connections. In this section, I
propose a methodology based on recent developments in network diffusion research
to study how exposure to different geographical collaborative networks could explain
the adoption of zebrafish as a model organism in Latin America and in other regional
scientific communities.

The theory that has best encapsulated the relationship between social
networks and behaviour change is Diffusion of Innovations Theory (DIT). The original
formulation of DIT dates backs to the early 1960s and the works of Everett Rogers
(1962) on technological innovations. The definition of diffusion put forward by Rogers
back then described four key elements. Diffusion, Roger stated, is “the process by
which (1) an innovation, (2) is communicated through certain channels (3) over time
(4) among the members of a social system” (Ibid 10). The notion of exposure in this
eyear definition is connected to the channels component (3), which Roger defines as
the “means by which messages get from one individual to another” (Ibid 17), including
interpersonal communications as well as mass media communication channels.
However, like Basalla’s diffusionist model, the early version of the theory was a
product of the human capital paradigm of the time. This means that rather than
focusing on the study of social networks, researchers using this model viewed
individuals as ‘independent agents’ and therefore considered that diffusion could be
studied through a series of measures such as the evolution of the number of cumulative adopters across time, the rate of adoption or the hazard rate\textsuperscript{10}.

In line with trends in the diffusion debated described above, recent developments in DIT have resulted in a greater focus on social networks. Particularly, the work of Thomas Valente (1996; 2005) had provided researchers with interesting mathematical models to study and measure how social networks affect behaviour and behaviour change. Keeping the theory’s premise that innovations spread through interpersonal communications, the new version of the theory put forward by Valente captures the relationship between exposure and social networks under the more dynamic concept of “network exposure”. Accordingly, social networks are considered the means by which innovations, which may originate in another community, are transported across communities and/or are diffused within the same community where it was invented (Valente 2010).

In practical terms, the concept of network exposure allows computing for each individual in a social system, the proportion or number of contacts in their individual social network (i.e. ego-network) that have already adopted a certain behaviour, practice or innovation, and whose diffusion is the object of study. If we were interested in observing smoking behaviour, for instance, network exposure would be the proportion of an individual’s friends who smoke.

Network exposure is calculated as follows:

\[ E_i = \frac{\sum w_{ij}y_j}{\sum w_i} \]

Where \( w \) is the social network weight matrix and \( y \) is a vector of adoptions. The denominator can be further excluded if one wishes to obtain a count instead of a proportion. For an actor (i.e. ego) that has three contacts (i.e. alters), network exposure (\( E \)) is therefore the proportion (or number) of those contacts who have adopted a particular innovation at or prior to ego’s own adoption (see figure 16).

\textsuperscript{10} The rate of adoption is commonly referred as the relative speed in which actors adopt a given innovation (Rogers 2003). The hazard rate refers to the instantaneous probability of adoption at each time representing the likelihood members will adopt at that time (Allison 1984).
In addition, the concept of innovation used by proponents of this approach is broad and is essentially associated with the diffusion of new behaviours among actors of a social system, which can refer to any type of actor (e.g. individuals, institutions or countries). For instance, using survey data and randomised computer simulations, network diffusion models have been used extensively in public health research (see Glanz, Rimer, and Viswanath 2008; Valente 2010; Andrews et al. 2014). Recently, some studies have expanded its scope by studying the diffusion of treaty ratifications (Valente et al. 2015), non-traditional banking models (Cuntz and Blind 2010), trade unions and social movements (Hedström 1994; Hedström, Sandell, and Stern 2000) as well as enterprise systems in the automotive sector (Millaire et al. 2009). In science studies, the application of network diffusion models has led some researchers to consider publications as objects of scientific innovation (see Gupta, Sharma, and Karisiddappa 1995) and co-citation patterns as the social vehicle that explains their diffusion (Kortelainen 1997; Gao and Guan 2012b). 

Figure 16. Personal network exposure from direct contacts (Valente 2005, 103)

I consider the adoption of the zebrafish as an object of scientific innovation, and based on the history of zebrafish research, I argue that its diffusion has been driven by exposure to networks of scientific collaboration. As described in Chapter 5, these networks often involve the exchange of resources including species and expertise. As such, I assume that exposure to networks of experienced collaborators (expressed in scientific co-authorships) could have had a key influence in the adoption of zebrafish as a model organism and therefore explain its diffusion within and across scientific communities since the publication of the results of the Big Screens in 1996.

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11 A thorough search of the relevant literature, however, showed there are no applications of diffusion models based on co-authorship networks. The only exception is the work by Cadarette and colleagues (2017) who used co-authorship networks to study the diffusion of methodological innovations in pharmaco-epidemiology. However, their work relies on standard diffusion measures such as the rate of adoption and the evolution of cumulative adopters and does not rely on the more dynamic concept of network exposure.
Nevertheless, while network exposure is an interesting proxy to measure collaborations based on the exchange of resources, it does not take into account the geographical dimension of social networks, which as seen previously is a key aspect to consider in diffusion studies. In order to make such a distinction, I propose the following procedure to compute individual scores of exposure to geographically different networks using the affiliation information stored in scientific publications.

**Computing exposure to geographically bounded networks**

The computation of network exposure returns a matrix of network exposure scores as number/proportion of direct contacts who adopted a given behaviour (in this case, the adoption of zebrafish as a model organism). By partitioning scientific collaboration networks into geographical communities at different levels (e.g. national, regional and international), spatial network exposure scores can be computed for each actor at each point in time. However, because regional and international communities may include duplicated contacts (i.e. national contacts included in regional collaboration networks), the different matrices of network exposures have to be subtracted to obtain unduplicated (i.e. cleaned) scores.

\[
\begin{bmatrix}
a_1 & a_2 & a_3 \\
a_4 & a_5 & a_6 \\
a_7 & a_8 & a_9 \\
\end{bmatrix} - 
\begin{bmatrix}
b_1 & b_2 & b_3 \\
b_4 & b_5 & b_6 \\
b_7 & b_8 & b_9 \\
\end{bmatrix} = 
\begin{bmatrix}
a - b_1 & a - b_2 & a - b_3 \\
a - b_4 & a - b_5 & a - b_6 \\
a - b_7 & a - b_8 & a - b_9 \\
\end{bmatrix}
\]

In the above example, matrix \(a\) contains network exposure scores (raw counts) of every ego from the whole network of direct contacts. Each row represents ego’s scores across different time points. That is, each column represents a time data point, where \(a_1\) represents an ego’s network exposure in \(t_1\), \(a_2\) in \(t_2\) and so on. Matrix \(b\) contains the network exposure scores of the same group of egos but relative to alters from their same country, with the same time range. The subtraction of both matrices returns scores that reflect raw international exposure scores.

\[
\begin{bmatrix}
c_1 & c_2 & c_3 \\
c_4 & c_5 & c_6 \\
c_7 & c_8 & c_9 \\
\end{bmatrix} - 
\begin{bmatrix}
b_1 & b_2 & b_3 \\
b_4 & b_5 & b_6 \\
b_7 & b_8 & b_9 \\
\end{bmatrix} = 
\begin{bmatrix}
c - b_1 & c - b_2 & c - b_3 \\
c - b_4 & c - b_5 & c - b_6 \\
c - b_7 & c - b_8 & c - b_9 \\
\end{bmatrix}
\]

Matrix \(c\) contains the network exposure scores relative to contacts from the same region as ego; including national contacts (raw regional exposure scores). To
obtain clean regional network exposure scores, the national exposure matrix ($b$) is subtracted from the raw regional exposure matrix ($c$).

\[
\begin{pmatrix}
d_1 & d & d \\
d_4 & d_5 & d \\
d_7 & d_8 & d_9
\end{pmatrix}
- \begin{pmatrix}
e_1 & e_2 & e_3 \\
e_4 & e_5 & e_6 \\
e_7 & e_8 & e_9
\end{pmatrix}
= \begin{pmatrix}
d - e_1 & d - e_2 & d - e_3 \\
d - e_4 & d - e_5 & d - e_6 \\
d - e_7 & d - e_8 & d - e_9
\end{pmatrix}
\]

Finally, to obtain a matrix of cleaned international exposure scores, the same procedure is repeated between the matrix of international exposure scores (raw) obtained in step 1 and the matrix containing regional exposure scores (clean) obtained in step 2\textsuperscript{12}.

This simple procedure yields three matrices of geographically bounded network exposure scores (e.g. national, regional and international) which can be added as dynamic attributes for each individual in the social system. Following this, the co-authorship network can be coerced into a longitudinal database that can be used to observe the influence of these network exposures upon actors’ individual adoption behaviour across time.

**Methods and data**

**Quantitative data collection**

The data was retrieved in October 2018 from the Scopus custom Extensible Markup Language (XML) database of the Centre for Science and Technology Studies (CWTS) of Leiden University.

In order to select publications that reflect the use of the zebrafish in biomedical research, an SQL query was designed that allows searching the zebrafish descriptors (included in the Medical Subject Headings (MeSH) curated by the NIH) in the abstracts of the publications\textsuperscript{13}. A total of 28,973 documents were extracted from Scopus including information on authors and their institutional affiliations.

\textsuperscript{12} When partitioning the network into groups, this technique replicates in a certain sense the procedure followed in the calculation of the E-I index. However, in this case, the computation of ties is done dynamically; that is, I consider the evolution of the network at the micro level over time.

\textsuperscript{13} Used descriptors: zebrafish, Zebra Fish, Zebra danio, danio rerio, Zebrafishes, Brachydanio rerio, D. rerio, B. rerio.
In addition, to validate the representativeness of the collection (that is, articles that reflect the use of the zebrafish as a model organism), a two-stage process was followed. First, the same query was replicated in alternative bibliometric databases – Web of Science (WoS) and PubMed – and in the online repository of publications developed by the Zebrafish Information Network (ZFIN). A total of 27,816 documents were extracted from WoS, 26,500 from PubMed and 24,453 from ZFIN.

Next, overlaps between the four databases were analysed. Low matching percentages were identified between Scopus, WoS and ZFIN. This is explained by the extensive coverage of scientific journals beyond the field of health sciences in the case of WoS, and by the inclusion of a large number of doctoral theses, dissertations and non-peer-reviewed publications in the zebrafish online repository. In contrast, with the publications collected from PubMed, I found an overlap of 94.7%, which confirms that the vast majority of publications collected in Scopus are medical research articles.

Second, to make sure that the selected publications referred to research that made explicit use of zebrafish as a model organism (be that as the main model or as a complementary one) the query and a small random sample of articles was reviewed and validated by an expert in zebrafish research.

**Sampling**

Research institutions were selected over individuals or countries as the main unit of analysis for three reasons. First, the so-called ‘collaborative turn’ in science means that research teams and collaboration networks have increased in size and that collaborations between institutions crossing national and disciplinary boundaries have become increasingly common (Olechnicka, Ploszaj, and Celińska-Janowicz 2018, 34).

Second, research institutions’ adoption behaviour is explained by the adoption behaviour of the scientists affiliated to that institution. This results from the handling of bibliometric data, which means that if a researcher adopts a scientific innovation, then by the definition his/her institution(s) of affiliation has also adopted it.

Third, since the goal is to produce geographically sensitive network exposure scores, computing these metrics at the level of individual researchers poses critical challenges given the mobility trajectories of researchers and the existence of multiple affiliations (Moed and Halevi 2014; Robinson-Garcia et al. 2019). In this sense,
although a co-authorship between two institutions might not necessarily reflect a collaboration between two or more researchers (see Katz and Martin 1997), multiple authorships are indicative of a knowledge diffusion process taking place between two institutions. Consider for a moment the temporary mobility of a young researcher working on an institution with no previous experience on zebrafish. In this case, the hosting institution has an extensive previous record of publication on zebrafish and the researcher's stay at this institution (as reflected in his/her publication record) eventually gives place to a double affiliation. The analysis of this mobility at the institutional level can reflect knowledge exchange processes triggered by training needs. That is, a collaborative link between the two institutions is captured correctly.

Unique research institutions were identified using their affiliation ID in Scopus, which is useful for distinguishing between institutions or departments that have the same name or when the same department has been cited differently (Elsevier 2019).

In terms of data sampling, following an approach consistent with previous studies (see Deville et al. 2015; T. Martin et al. 2013), I inspected the distribution of the number of institutions per paper and the cumulative density function in order to determine the probability of the relationship between documents and number of institutions. A cut off of papers with no more than 15 institutions was chosen after observing a deviation from the power-law fitting line roughly at this point (see figure 17). Applying this initial filter returns a population of 8,512 research institutions publishing 28,624 papers in total. In addition, as my focus is the analysis of diffusion via collaborative links, single authored publications were excluded from the sample. The combination of these two filters returned a final collection of 17,802 papers, which means that 62.19% of the initial publications extracted are considered in this study.
Figure 17. Cumulative Density Function of number of institutions per paper. The vertical line falls at 15 institutions corresponding roughly to the point where the distribution deviates from the power.

Data structuring

I then structured the data as a longitudinal co-authorship network composed of 8,077 nodes, 21 time points (1996-2016) and 158,167 co-authorship events in total.

Following the structures applied in DIT network models, to model the diffusion process I work with the concepts of ‘user’ – i.e. an actor who adopts a given innovation – and ‘time-of-adoption’ (TOA) – i.e. an indicator of when this change occurs. It follows that a research centre is considered a user when it adopts zebrafish as a model organism. Adoption as such is considered effective when the same centre has published in more than one year, its TOA being the second year in its zebrafish publication record. Of the 8,077 nodes that make up the network, 3,691 institutions meet this user criterion, which represents 45.67% of the total institutions that are part of the sample. The rest of the institutions (4,386) are considered non-users, although their collaboration networks are included in the dissemination model too.

I calculated a lagged exposure of one year for every research institution for each point in time. In epidemiology, exposure lagging means the exclusion of exposure in a time point prior to the registration of an outcome. This is motivated by the assumption that such outcome might have occurred before its registration and that exposure at time of registration did not contribute to the case (Rothman, Lash, and Greenland 2008, 301). Calculating lagged exposure for my analysis is appropriate as the TOA of every research institution refers to its second year of
publication on zebrafish. In this sense, co-authorship networks taking place before the TOA could have contributed to the adoption of zebrafish as model organism.

To compare trends between the different scientific communities, lagged exposures were normalised and computed as the proportion of users present in an institution’s collaborative network at $t-1$, and who adopted zebrafish prior or at that institution’s TOA. In other words, a lagged international exposure of 0.5 in 2001 for institution ‘A’ means that half of its collaborators in the year 2000 had already worked with the zebrafish as reflected in their publication record.

A matrix containing dynamic and static attribute data for all nodes in the network was produced, including the following variables:

**Table 3. Model variables and justification.**

<table>
<thead>
<tr>
<th>Static attributes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of adoption (TOA)</td>
<td>Computed for each user by taking the second year of their publication record on zebrafish (not from the sample but from the whole dataset). This variable is necessary to be able to model the diffusion process since it is later taken as the dependent variable of the model.</td>
</tr>
<tr>
<td>Country</td>
<td>Institutions’ affiliation country. This variable is used to analyse the spatial dimension of collaboration networks as described above.</td>
</tr>
<tr>
<td>Mobility status</td>
<td>The share of internationally mobile researchers in each institution. The inclusion of this variable is motivated by my interest to observe the influence of international mobility in the diffusion process (another practice of internationalisation) and is the result of a separate analysis of the entire corpus of publications of zebrafish authors (see Chapter 7). The analysis focused on the change in international affiliations recorded in more than 2 million publications that include publications beyond zebrafish research. A scientist is classified as ‘mobile’ when he/she published in at least 2 different countries throughout his career.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dynamic attributes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ego-network size</td>
<td>The size of the ego-network at each point in time.</td>
</tr>
<tr>
<td>Pub year</td>
<td>The year of publication.</td>
</tr>
<tr>
<td>Network exposures</td>
<td>Exposure to national, regional or international networks of experienced collaborators (lagged exposure of 1 year). Exposure is computed as a raw count expressing the total number of contacts in ego’s network at $t-1$ who adopted zebrafish prior or at ego’s own TOA.</td>
</tr>
</tbody>
</table>

**Limitations of the model**

Though this is a strong model to study how networks intervene in diffusion processes, it should be noted that many choices inform the construction of statistical models, which can lead to different empirical results. First, only international mobility is considered a factor of influence beyond social networks. Besides considering the
fixed effects for time (e.g. some years have witnessed a larger number of adoptions), other external factors could be included in the model to control for the effects of social networks. In any case, the model includes three different types of network exposures and considers the risk effects of observing the outcome in groups of institutes that are not exposed to expert-based networks.

Second, using yearly intervals as TOA can force the calculation of exposure contemporaneously (Valente 2010). In this sense, using the year of publication as the unit of analysis poses some challenges to analyse the diffusion process. Institutions often publish more than one publication per year and it is not always easy to determine which paper was published first (i.e. the information about the month of publication is missing). Moreover, in numerous cases, reviewers and journal editors delay publications, and researchers often divide results from one experiment into different publications to maximise their productivity. Because of this, the model does not identify for each institution a unique paper reflecting its TOA (that is, an institution’s seminal paper on zebrafish) but rather considers all types of interactions – which are of course reflected in the papers – taking place in a given year. This further illustrates a key conceptual difference in diffusion studies based on bibliometric data. In citation-based analyses, papers themselves are considered the object of scientific innovation. In contrast, in diffusion analyses based on co-authorship networks, the innovation is determined by the parameters of the search query, whereas the papers contain the social interactions (i.e. co-authorships) that drive the diffusion.

Third, as noted previously, arbitrary decisions have been made to define what counts as a user in this social system. Whereas in diffusion studies based on surveys the research subjects identify themselves as users or non-users, in bibliometrics the decision rests on the researcher who identifies adopters ad-hoc based on existing data. Using an arbitrary cut-off parameter to identify users greatly influences the boundaries of the community of users and consequently affects the computation of network diffusion metrics.

Four, it should be acknowledged the differences that exist within and across the selected communities. For instance, in Latin America or peripheral Asia-Oceania, it is more likely to find a greater divergence between national scientific systems in terms of their size and levels of scientific productivity. This difference may explain why network exposures have a higher effect in these regions: some research institutes
from small national scientific communities maintain very high levels of international network exposure across the years compared to its neighbours from other countries.

Lastly, network exposure modelling is very flexible as it allows including other mechanisms of social influence. Although the above model includes three types of geographical network exposure, they nevertheless refer to the same type of social influence: direct collaboration, though no collinearity was registered. In this sense, it will be interesting to observe how other types of network exposure, such as structural equivalence (i.e. the extent to which two people occupy similar positions in the network) influence adoption behaviour as well. Moreover, the use of co-authorships also means data is undirected and information about the direction of that social influence is missing.

Data modelling

To model the diffusion process in Latin America and compare it with other communities, I proceeded to group the different research centres according to the region to which they belong. Six scientific communities were identified according to three criteria. First, I attended at the classification of regions made by the International Zebrafish Society (IZFS), which considers the distribution of PIs regionally. At the time of conducting this analysis, IZFS classified zebrafish communities into four large scientific regions: (1) Asia and Pacific, (2) Europe and Mediterranean countries, (3) Mexico, Central and South America, Caribbean, and Africa and (4) United States and Canada.

Second, I took into account the existence of regional collaboration networks such as LAZEN in Latin America (composed by 8 countries\footnote{The countries that take part in the network are Argentina, Brazil, Chile, Colombia, Ecuador, México, Peru and Uruguay.}) and the EuFishBioMed network in Europe (formed by 38 countries), funded by the COST programme. Therefore, in the case of Latin America, this means that Caribbean and African countries were excluded from the model given the low participation of these countries in the total zebrafish scientific output (<1%). Third, to consider centre-periphery dynamics within each region, larger regions were further divided into ‘core’ and ‘peripheral’ communities where the core is responsible for more than 60% of publications produced in that region. This affected namely Europe and Asia-Pacific.
regions. For their part, North American and LAZEN communities can be considered core and peripheral communities of the American continent.

To analyse how collaboration networks influence adoption behaviour, the dataset was reshaped as longitudinal dataset displaying the different network exposure scores for every institution across time. Adoption behaviour was recorded as a dummy variable that is equal to 1 when a research institute adopted zebrafish as a model organism in that time point. Adoption behaviour was regressed on the percentage of national, regional and international expert-based collaborators present in each research institution’s collaboration network at each point in time, controlled by the share of international mobile researchers present in that institution and the fixed effects of time.

To identify which of the above variables best explain adoption behaviour in each of these communities, I followed a decision tree analysis, a type of supervised Machine Learning technique. Decision tree builds regression models in the form of a tree structure, breaking down a dataset into smaller datasets to find the variables (or combination of them) which best explain the target phenomenon. This results in a tree with decision nodes (or terminal nodes) which describe the hierarchical importance of the variables that have a significant effect upon the dependent variable. This allows me to see whether adoption behaviour in each community is determined by exposure to a particular geographical network or by a combination of different collaborative networks, and therefore contribute to the debate in diffusion network studies on the relative importance of the local milieu vis-à-vis global pipelines discussed earlier in this chapter.

**Findings**

The analysis of results proceeds in two steps. First, I describe the evolution and spatial structure of the zebrafish collaboration network, and I focus on some of the key research institutions that took part in the 1996 Big Screens. Second, I model the diffusion process of zebrafish by testing how the different geographical collaboration networks explain the adoption of this model in Latin America as well as in other regional communities that occupy core or peripheral positions in the global scientific network.
The zebrafish co-authorship network (1996-2016)

Figure 18 shows four snapshots of the evolution of the co-authorship networks of zebrafish research from 1996 to 2016. Each node (circle) represents a research institution and the links between them (edges) reflect a paper signed in collaboration between any pair of institutions. The thickness of the edges expresses the number of paper co-authored between them where the thicker the edge, the larger the number of paper co-authored by these two institutions.

The size of the nodes have been adjusted by their weighted degree centrality, which expresses the sum of the number of edges (i.e. collaborations) each institution had during the period of reference; the bigger the node, the more central their position in the collaborative network. Lastly, nodes’ colours represent the scientific community each institution belongs to:

- Blue: EU-COST region\(^{15}\)
- Green: North America (U.S. and Canada)
- Yellow: Asia-Pacific (ASOC)
- Red: LAZEN-Latin America

In the four time-periods, the zebrafish collaboration network appears to be dominated by one giant component. The rest of the network is composed of smaller components (mostly dyads), disconnected from the central network and there are no second large components. Accordingly, I only display the collaborative network corresponding to the giant component for each of the four time-periods.

One of the first observations emerging from the visual inspection of figure 18, is the clear spatial clustering pattern displayed in the networks. Nodes (i.e. institutions) tend to be clustered around nodes from their same region and this tendency becomes clearer with the passing of time. By 2011-2016 the network is split into two large well-defined geographical clusters (North America and Europe) and two smaller, peripheral and less densely connected clusters (Asia-Pacific and LAZEN).

---

\(^{15}\) This is a region formed by the 38 member countries of the COST program, the majority of which are European.
Table 4 presents the summary statistics of the four giant components. As can be seen, the four components are largely representative of the full zebrafish collaborative network in each time period. Particularly, the network size (i.e. the total number of nodes present in the giant component relative to the whole network) increases over time: ranging from 89% in 1996-2000 to 96.8% in 2011-2016. Moreover, the interactions between nodes (measured in terms of number of edges or links) in each network also tends to increase over time. These figures coincide with the size of the network component reported by Newman for biomedical fields (Newman 2001b; 2001a).

On the other hand, the network density, which indicates the proportion of all possible ties that are actually present, is low and decreases over time. In the early years of the diffusion process (1996-2000), only 1% of all possible ties in the network were present whereas in 2011-2016, the graph density decreases more than ten times that measure. This is expected because the networks are composed by relatively high number of institutions and, as the time passes, more actors are incorporated into the network thus reducing the probably of interactions between nodes. This is observed clearly in the decrease of the network centralisation (from 0.11 in 1996-200 to 0.073 in 2011-2016), which indicates the extent to which the network is dominated by a small group of centralised nodes.

Table 4. Summary statistics. Zebrafish co-authorship network.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Network size</td>
<td>604 (89.6%)</td>
<td>1,310 (93.0%)</td>
<td>2,612 (95.1%)</td>
<td>1,926 (96.8%)</td>
</tr>
<tr>
<td>Total publications</td>
<td>1,473</td>
<td>3,418</td>
<td>6,634</td>
<td>11,264</td>
</tr>
<tr>
<td>Edges</td>
<td>3,598 (97.4%)</td>
<td>10,144 (98.6%)</td>
<td>24,950 (99.0%)</td>
<td>75,028 (99.6%)</td>
</tr>
<tr>
<td>Graph density</td>
<td>0.010</td>
<td>0.006</td>
<td>0.004</td>
<td>0.002</td>
</tr>
<tr>
<td>Avg. degree</td>
<td>5.48</td>
<td>7.31</td>
<td>9.17</td>
<td>12.86</td>
</tr>
<tr>
<td>Avg. Weighted</td>
<td>7.63</td>
<td>9.11</td>
<td>11.65</td>
<td>70.31</td>
</tr>
<tr>
<td>degree centralisation</td>
<td>0.12</td>
<td>0.07</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td>Betweenness</td>
<td>0.16</td>
<td>0.10</td>
<td>0.05</td>
<td>0.04</td>
</tr>
</tbody>
</table>

To allow a more detailed visual inspection of the networks, in figure 19 (panels a-d), I show again each network with a threshold of 40 for nodes’ weighted degree. The higher network density in the period 1996-2000 is largely explained by the intense collaborations between the institutions that took part in the aforementioned Big
Screens project, including the University of Oregon and the Max Planck Institute for Developmental Biology (MPIDB) (see figure 19.a). Moreover, these two institutions report the highest weighted degree centrality during this period (see figure 20), although the University of Oregon reports a higher betweenness centrality scores, which indicates this institute played a more active role as a bridged between otherwise separated members of the network in the early years of the zebrafish community (see figure 21). In general, the intense collaborations taking place in the giant component between the most central institutions are a key feature of the early years of zebrafish genetics research. As seen in Chapter 5, the international collaborations between this small numbers of institutions set the ground for the infrastructures of the incipient zebrafish community.
The previous statement seems to be confirmed by the evolution of the network since 2001. During the next five years (2001-2005), a displacement is observed of the central institutions towards the borders of the network and the formation of the first small geographical clusters (figure 19.b). This confirms the key role the pioneering institutions played in the widening of the zebrafish community in their regions and internationally. In Europe (blue nodes), the MPIDB became a key collaborative partner for many research institutions in this region. In North America (green nodes), the Harvard School of Medicine together with the rest of institutions that formed the Boston group during the Big Screens project became the main point of reference for most U.S. research institutions, in detriment of the University of Oregon (see figure 20). However, the latter maintained ties with U.S based institutions and added new connections with research institutions in China and Taiwan, which is indicative of its continued international reputation and its role as a broker in the collaboration network (see figure 21). During this period, new central research institutions emerge in the
collaboration network such as the Japanese Science & Technology Agency and the University of Tokyo.

Figure 20. Weighted degree scores distribution in the four giant components.

Figure 21. Betweenness centrality scores distribution in the four giant components.
In the following 10 years (figures 19.c.-d), new collaborative clusters in Asia-Pacific (yellow nodes) and, to a lesser extent, Latin America (red nodes) emerged. However, unlike the European cluster, these new ‘peripheral’ clusters seem to be mostly country-based (e.g. Japanese, Singaporean or Brazilian institutions). In general, as the network grew in size, less institutes perform a key role as brokers (figure 21). In addition, the low weighted degree centrality observed in peripheral communities such as LAZEN and Asia-Pacific indicates that research institutes in these regions are indeed located at the periphery of the global zebrafish collaborative network (see figure 20).

**Diffusion of zebrafish as a model organism in the collaborative network**

When looking at the evolution of the number of (cumulative) adopters (figure 22), one can observe that a slow and progressive diffusion process has driven the use of zebrafish in life sciences research within and across regional communities. In general, in those communities where institutions had none or little interactions with the most central institutions of the early zebrafish network, the curve of cumulative adopters indicates a rather delayed diffusion process, most notably Latin America and Asia-Pacific; both located at the periphery of the collaboration network.

The above analysis, although insightful about the evolution of the structure of the collaboration zebrafish network, does not tell us much about the importance of these networks in the adoption of zebrafish as a model organism and about the knowledge diffusion that took place in these collaborations. In other words, it does not explain the extent to which these collaborative links were established between experienced ‘users’ and ‘non-users’ of the model. More importantly, it does not provide insights on the relative importance of geographically bounded collaborative networks in the adoption of the model by research centres in each scientific community. Accordingly, in what follows I present the summary statistics and findings of the diffusion model I built to analyse such dynamics.
Table 5 displays the terminal nodes of the classification tree regressions\(^{16}\) and the model rules; that is the combination of variables and their probability and coverage of observations in each of the selected communities. Overall, it shows that collaboration networks have an influence on adoption behaviour, explaining a large number of adoptions on average (i.e. goodness). Goodness, in other words, means the capacity that the models run in each community have to classify adopters and non-adopters above an established threshold of 0.5%. As shown in the table, the models’ goodness are between 77-93%, thus correctly classifying a large number of cases. However, their capacity of predicting adoptions is very modest as probabilities are notably low for the first nodes of the tree (i.e. Adopted prob.). This also shows that, diffusion through collaborative networks does not necessarily adjust to an epidemiology type of diffusion process.

National exposure seems to be the main explicative variable, albeit in combination with other variables. For instance, starting at the bottom in the case of North America, the last rule says that institutions with 11% or less of national research

\(^{16}\text{Classification trees is a type of decision tree analysis that is used when the predictive outcome is of type categorical. In this case, the categories are adopted (1) and not adopted (0).}\)
institutes with experience in the use of the model in their collaboration networks had a probability of adoption of 0.36. The cover measure shows that only 5% of institutions in the model fall into this rule. In turn, for 84% of cases, there is a 4% of probability of adoption when national experienced collaborators represent about 11% of the institutes’ ego-networks and when the year of adoption falls within the 1996-2010 period. In general, the results show that the most explicative nodes (i.e. combination of variables) in core communities often include exposure to national collaborators with previous experience in the use of the model.

In EU-COST (core), there exist a 2% probability that non-users adopt zebrafish as model when their collaboration networks are formed by less than 12% of experienced users from the same country. In this case, however, the effect of national exposure is accompanied by the fixed effects of time as well as by the presence of a small percentage (4%) of regional users in the collaboration networks. The second rule, for instance, shows that having a small percentage of regional users, together with the effects of specific years, increases the probability of adoption to 10%, and this covers 15% of cases. In fact, in no other community exposure to regional networks seems to have an effect upon adoption, which is indicative of the influence of the EU-COST network programme.

A similar situation to that of North America and core EU-COST is observed in Asia-Pacific (core), where research institutions have a 2% probability of adoption, although in this case exposure to international users and time accompany the effects of national exposure. Here it is interesting to observe that, starting at the bottom, the second rule shows that there is 0.42 probability of adoption when networks are composed by less than 12% of national experienced collaborators and 37% or more of international experienced collaborators, along with the fixed effects of time.

In LAZEN, as well as in other peripheral communities where the pace of diffusion has been slower (e.g. Asia-Pacific and peripheral EU-COST), the effects of national network exposure and the time of adoption are accompanied by exposure to international experienced users. In the LAZEN region, there is a 2% of probability of adoption when at least 3% of collaborators are national institutes with previous experience. As with the other cases, this is accompanied by fixed effects of time, but also by the presence of a significant share of international collaborators (less than 57%). In the peripheral communities of Asia-Pacific and EU-COST, the shares of international experienced collaborators accompanying the effects of national
exposure are also notable, yet smaller (less than 37% and 16% respectively). At first sight, this could indicate that, compared to other peripheral communities, international network exposure has a bigger influence in peripheral communities. However, the low levels of probabilities indicate that the influence of spatial networks upon adoption behaviour in the region is considerably low. Moreover, the precedence of national network exposure in the decision tree discards the existence of a clear pattern of international dependency in this process explained by a geographical concentration of scientific expertise in the zebrafish collaboration network. In fact, when the probabilities of adoption are higher, variables explaining adoption are exposure to national networks and/or the fixed effects of time.

The fact that international exposure is comparatively more relevant in peripheral communities than core communities (both in terms of the hierarchy in the tree and the share of collaborators in the institutions’ networks) – though not a strong predictor of adoption behaviour –, indicates an importance of these networks beyond the diffusion process of zebrafish as a model organism. As such, in the next section, I explore further the meaning of these networks from the perspective of South American zebrafish researchers.
Table 5. Decision tree. Each row represents a terminal node. Variables are organised in hierarchical order within each node.

<table>
<thead>
<tr>
<th>Community</th>
<th>Adopted prob.</th>
<th>Rule</th>
<th>Cover</th>
<th>Goodness</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>0.04</td>
<td>when lagged_nat_expo &lt; 0.11 &amp; year is (1996 ~ 2010)</td>
<td>84%</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>0.18</td>
<td>when lagged_nat_expo &lt; 0.11 &amp; year is (2011 ~ 2016)</td>
<td>11%</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>0.36</td>
<td>when lagged_nat_expo &gt;= 0.11</td>
<td>5%</td>
<td>0.75</td>
</tr>
<tr>
<td>LAZEN</td>
<td>0.02</td>
<td>when lagged_nat_expo &lt; 0.035 &amp; year is (1996 ~ 2013) &amp; lagged_int_expo &lt; 0.57</td>
<td>91%</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>0.20</td>
<td>when lagged_nat_expo &gt;= 0.035 &amp; year is (2006, 2008, 2010, 2012)</td>
<td>1%</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>0.23</td>
<td>when lagged_nat_expo &lt; 0.035 &amp; year is (2014, 2015, 2016)</td>
<td>5%</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>0.39</td>
<td>when lagged_nat_expo &lt; 0.035 &amp; year is (1996 ~ 2013) &amp; lagged_int_expo &gt;= 0.57</td>
<td>1%</td>
<td>0.75</td>
</tr>
<tr>
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</tr>
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<tr>
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<tr>
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<td>when year is (2012 ~ 2013)</td>
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<td>0.36</td>
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International collaborative networks: exposure to what exactly?

The previous quantitative analysis did not intent to determine the reasons why research institutions choose zebrafish as a model organism. Adoption of a model organism is a multifactorial phenomenon where scientists make strategic trade-offs to emphasize some criteria over other – for more information on this I recommend Dietrich et al. (2020). Yet, as seen in the previous chapter, internationalisation dynamics played a key role in the construction of zebrafish as a model organism. Particularly, internationalisation practices enable some of the criteria often pointed out by scientists to justify their choice for this model such as the ease of supply, its standardisation, and widespread access to epistemic and material resources.

Instead, my main motivation for building such a diffusion model was to analyse the extent to which geographical collaboration networks in Latin America – namely engagement with international experienced collaborators – acted as vehicle for facilitating these strategic choices compared with trends observed in other scientific communities. In doing so, I used co-authorships to study how exposure to international experienced collaborators might have influenced the diffusion of zebrafish in the LAZEN region. This was motivated by findings of Chapter 5 that described knowledge transfer mechanisms in the zebrafish community via collaboration networks. There I noted how exchanges of resources – either in the form of training, live stocks or prestige – taking place between partners are often formally credited in the form of joint publications. Nevertheless, as stated elsewhere (see Katz and Martin 1997; Laudel 2002), co-authorships should remain as intended. That is, no more than a proxy to study collaboration and diffusion dynamics in science.

The results of the regression model showed that for LAZEN institutions, adoption was mostly driven by national network exposure. This means that for a research institute to adopt zebrafish as a model organism, it only needed the presence of a very small percentage of national collaborators in their individual networks who had previous experience in the use of the model. However, this trend was present in other scientific communities, not just in LAZEN.

In those communities where the pace of diffusion has been slower (Latin America being one of them), the effects of national network exposure on adoption were also accompanied by exposure to international experienced users. The results
of the regression tree indicate, nonetheless, that engagement with international peers did not contribute to adoption with the same strength that collaboration with national peers did. Yet as international collaborators often represent a large share of adopters in the collaborative networks of Latin American institutions, it becomes imperative to further inquire about the purpose of these international partnerships. In short, I sought to find out about the meaning of exposure by asking: what are South American institutes exposed to in these international networks?

In general, the analysis of interviews with zebrafish South American researchers shows that exposure to international networks has little to do with access to novel knowledge or ideas. For instance, when asked about the way research questions are usually designed when working with international partners, a Chilean scientist responds:

For us there is usually two types of situations. On the one hand, we share a common idea and then we know that part of that idea can be developed abroad – because they have the fishes or the technology to do so – and the other part can be done in our lab. In most cases though, we have an idea and we want to conduct an experiment. In those cases, I usually contact a researcher abroad and tell him: ‘I have this idea and I want to do it this way, but I need the microscopic [technology] to do it at the speed I want’. I then ask him if I can send a student to his lab to conduct the experiments (PI-Chile-1 2018).

This is not exclusive of zebrafish research. All the researchers interviewed for this project, working either on zebrafish or a different model organism, highlighted the technical dimension as the most valuable aspect of their international collaborations. This coincides with the analysis conducted in Chapter 3, where I explained how the transformation of the life sciences into a more technological-driven field has rendered international collaborations necessary for South American scientists to conduct research. Moreover, when asked about the reasons they think their international partners choose to collaborate with them, most of the zebrafish interviewees stress the high level of training of South American researchers and their creativity which results from their experience working under structurally difficult situations. In this sense, local training and novel ideas become a bargaining chip for these laboratories to access the material infrastructures of their collaborators in North America and Europe (interviews with PI-Chile-1 2018; PI-Chile-2 2018; PI-Chile-3 2018; PI-Argentina-9 2018; PI-Uruguay-4 2018).
In addition, as explained by some interviewees, demands by funders or journal reviewers to complement or replicate results achieved in one model in a different one is another key reason why international collaborative networks are formed. As a result of this, the zebrafish transforms into a strategic resource enabling interdisciplinary collaborations (not only with the local milieu but also with research institutes in other countries). In turn, this increases researchers’ chances of accessing funds and/or publications (interviews with PI-Chile-2 2018; PI-Argentina-7 2018). As one researcher acknowledged: “What I look in these international collaborations is a complementarity of models that would eventually help me to access an international grant” (PI-Uruguay-1 2018). Therefore, collaborative networks are formed for reasons beyond scientific interest and reflect the strategic behaviour of zebrafish researchers.

The notion of exposure for Latin American zebrafish researchers reveals itself when researchers talk about experiences of international collaboration. In general, what I noted from these conversations is that international collaborations are a key asset for researchers, but they are seldom motivated by the prospects of gaining access to concentrated expertise. What South American zebrafish researchers are often exposed in these international collaborative networks are not novel ideas but key resources (e.g. tools, techniques, mutant lines, wild type livestock, funding and even prestige) which they do not have access to on a daily basis. Exposure, in other words, is a practice of approximation to more advantageous structures. In small peripheral communities, these structures are more likely to be located elsewhere making international collaboration crucial. Therefore, while collaborative networks among geographically dispersed communities are a major exponent of the research ethos of model organism communities, these networks cannot be regarded simply as genuinely altruistic; they also constitute reproductions of the power structures derived from the social organisation of scientific labour worldwide.

This is not to say that, experiences of internationalisation (including collaboration and mobility) do not facilitate an exposure beyond access to material infrastructures and/or financial resources. In this sense, one of the main limitations of the previous diffusion model is that it focuses on research institutions and therefore ignores the individual trajectories of researchers. The PIs interviewed for this project, for instance, often stressed the value of international mobility for their students and young researchers (interviews with PI-Chile-1 2018; PI-Chile-2 2018; PI-Chile-3 2018; PI-Argentina-9 2018; PI-Uruguay-1 2018; PI-Uruguay-4 2018). However, in their view,
this exposure has less to do with access to novel knowledge (which, as they recognised, is increasingly accessible online, unlike when they started their career), but to be exposed, as one researcher put it, to “different strategies about how to view science and how to be successful” (PI-Chile-2 2018).

For the early adopters of the model in South America, experiences of internationalisation allowed them to seize the strategic importance of the model early on, develop a niche of research and eventually form local expertise in their own countries. The importance of these international trajectories is also considered a fundamental aspect of the constitution of the LAZEN network. As stated in the report of the first LAZEN meeting, zebrafish research started in Latin America in 1998 when young Latin American researchers returned from their postdoc abroad and set up their own laboratories in their home countries (Allende et al. 2011, 32).

A plausible explanation for the importance of national networks in the diffusion model could be found in the career paths of researchers. Many of the pioneers established the first zebrafish labs in the region after a training period abroad. The students they formed eventually underwent a similar internationalisation trajectory (interviews with PI-Chile-1 2018; PI-Chile-2 2018; PI-Uruguay-1 2018). In both cases, internationalisation remained a key feature of their research work, although the nature of exposure seems to differ between these early and late adopters. As informational infrastructures increasingly allow a more rapid access to novel research developed elsewhere on the globe, access to more advantageous material infrastructures had continued to frame experiences of exposure in the global diffusion of zebrafish as a model organism, especially for Latin American researchers.

Overall, in the LAZEN community, exposure to networks of international collaborators constitutes a practice of approximation to more advantages research infrastructures and technologies. These networks indeed reflect the asymmetries and dependencies derived from the social organisation of scientific labour worldwide. Nevertheless, exposure to international networks has little to do with access to novel and concentrated scientific expertise. In turn, local training and novel ideas are, in many cases, the bargaining chip that South American labs use to access geographically concentrated material infrastructures.
Discussion

The publication of the results of the Big Screens – the first international collaborative project on zebrafish research – in 1996 not only consolidated this little fish as a strong candidate for large-scale genetic analysis, it also opened a vast pool of resources for future zebrafish researchers across the world. Collaborative networks, which constitute a key pillar of model organisms’ research ethos (R. E. E. Kohler 1994; Rhee 2004; Leonelli and Ankeny 2012; 2015; Bos et al. 2007), are thought to have played a key role in the diffusion of this novel model organism across spaces of scientific practice. Furthermore, such diffusion has developed in a context which scholars have described as one where the growth of collaborative research in general has not brought about a more equitable distribution of scientific competence, but rather its concentration (Gibbons 1994; Olechnicka, Ploszaj, and Celińska-Janowicz 2018; Wagner and Leydesdorff 2005).

In diffusion studies, the persistence of power structures in the global scientific network has prompted the renewal of centre-periphery explanations to account for the uneven diffusion of knowledge and expertise across geographies. More recently, this has led to new discussions around the relative importance of global networks vis-à-vis interactions with the local milieu as drivers of scientific ideas and innovations. In general, the emphasis on the role of social networks is a shared feature among competing theories of knowledge diffusion in science. This common point has transformed the notion of exposure – a key feature of diffusion research – into a more dynamic concept and has eventually led to a new diffusionist hypothesis, where social networks and the power dynamics of space are key explanatory dimensions to be studied.

In this chapter, I set out to analyse three aspects connected to this hypothesis. First, relying on insights from network diffusion models, I analysed the spatial structure of the zebrafish collaboration network and I studied the role of these networks in the adoption and diffusion of zebrafish as a model organism in Latin America and other regional communities. Second, in order to take into account the spatial dimension in this analysis, I developed a methodology to compute and measure exposure to distinct geographical collaboration networks using bibliometric data. Third, the problematisation of scientific internationalisation led me to revisit the notion of exposure from a critical perspective. Using extracts from semi-structured interviews...
with South American zebrafish scientists, I examined the meaning of exposure to international collaborative partners and the power dynamics around these networks.

Results from the analysis of co-authorship networks at the institutional level expanding over a period of 20 years since the Big Screens, showed that geographical networks are a key feature of global zebrafish research. Results of the diffusion model also revealed exposure to networks of experienced national collaborators is the main explicative variable but often accompanied the fixed the effects of time and exposure to other geographical networks of collaborators. In the peripheral communities where the pace of diffusion has been slower, such as Latin America, the effects of national network exposure and the time of adoption are accompanied by exposure to a relatively higher share of experienced international collaborators compared to core communities in North America and Europe. However, I did no find clear pattern of international dependency in this process explained by a geographical concentration of scientific expertise in the zebrafish collaboration network.

The analysis of interviews further showed that exposure to networks of international collaborators for South American zebrafish researchers has less to do with exposure to novel ideas and more with access to privileged material infrastructures resulting from the social organisation of scientific labour worldwide. In other words, international collaboration constitutes a practice of approximation to more advantageous material structures, not concentrated expertise. This is far from a trivial point because in diffusion research we tend to assume that the currency of such exposure are ideas or innovative practices, instead of power dynamics such as material infrastructures, funding and prestige.

On the other hand, a plausible explanation of why national network exposure is hierarchically more important than international network exposure in Latin America (and in other communities) could be found in the career paths of researchers and their mobility trajectories. In this region, mobile researchers formed the first zebrafish labs. These labs helped training a pool of young researches who, after some period working abroad, eventually formed their own labs. This process facilitated the establishment of local and global linkages that provided researchers with access to key resources. While mobility trajectories are the key vehicle to forge collaborative networks between geographically distant research actors, they are also strongly connected with perceptions of excellence in scientific research. In the following chapter, I take a step further in the study of diffusion to investigate how international mobility trajectories
interact with the expectation of researchers as active contributors to the community’s knowledge infrastructures.
Chapter 7: International Mobility and Research Excellence in Zebrafish Research

Introduction

In this final empirical chapter, I explore the relationship between internationalisation and excellence in zebrafish science. In model organism research, excellence is synonym with contributing to knowledge infrastructures, including livestock centres and genomic databases, thus helping to diffuse these models within and outside their scientific communities (Leonelli and Ankeny 2012; 2013; 2015). The literature on excellence in science is rich and has vastly documented the connection between international mobility and researchers’ productivity and recognition (renowned studies include Mahroum 1999; Ackers 2008). However, we still have little understanding of how notions of research excellence are connected to internationalisation dynamics in the life sciences and in model organism research in particular.

In Chapter 5, I discussed how internationalisation dynamics intervened in the construction of zebrafish as a standardised model for life sciences research. I described the early efforts developed by the small zebrafish community to present this little fish as a strong candidate for scaled-up genetic analysis and the community infrastructures envisaged to facilitate the exchange and conservation of livestock worldwide. I discussed how international stock centres are often considered key instruments for maintaining the scientific value of model organisms and a tangible indicator of the collaborative ethos often associated with these research communities. By focusing on the experiences of South American zebrafish researchers, however, I showed how complex dynamics of dependency and empowerment are present in practices of resource exchange that challenge the vision of these communities as uniform and harmonious global ecosystems, where researchers share species and resources freely and unselfishly. Moreover, instead of a centralised and international distribution platform, informal collaborative networks (many of which expand across borders and reflect power imbalances too), have allowed researchers in the region to access stocks of wild type and transgenic fishes and conduct research on this novel organism.
In Chapter 6, I took a step forward to examine more closely the role of these collaboration networks in the diffusion of zebrafish in Latin America vis-à-vis other scientific communities. Building on insights from research on knowledge diffusion, I described the geographical structure of the zebrafish collaboration network and I investigated the extent to which the adoption of zebrafish as a model organism by Latin American research institutes relied on collaboration with networks of experienced international users of the model. The results of a large-scale bibliometric network analysis showed that adoption behaviour among research centres results from an exposure to a combination of national and international collaborative networks, where direct collaboration with a small share of experienced national collaborators stands out as an explanatory factor. In LAZEN and other peripheral communities, the effects of national network exposure are accompanied by exposure to international experienced users. A close inspection of the nature of these collaborative linkages further showed that for South American zebrafish researchers, exposure to networks of international collaborators has less to do with exposure to novel ideas and more with access to privileged material infrastructures. In other words, in the diffusion of zebrafish in this region, international collaboration constitutes a practice of approximation (i.e. getting closer) to more advantageous material structures, not concentrated expertise.

My aim in this chapter is twofold. Firstly, I want to study how practices of biological data curation shape the notion of excellence in the zebrafish community at a global scale. Secondly, I seek to observe how international mobility – a key practice of scientific internationalisation – interacts with researchers’ contributions and visibility within the zebrafish online database. Like in the previous two chapters, I focus on the experiences of South American researchers aiming to unpack dynamics of dependency and empowerment present in the interaction between scientific internationalisation and the notion of research excellence in zebrafish research.

The chapter is organised as follows. In the first section, I review existing literature on the topic of scientific mobility and I provide insights into the notion of research excellence as viewed from the periphery and within model organism science. In section two, I discuss the case of the Zebrafish Information Network (ZFIN) – the international database of genetic and genomic information on zebrafish. I describe practices of biological data curation taking place at this institution with the aim of examining how they shape the notion of research excellence in the zebrafish
community. In section three, I move on to study the interaction between international mobility and research excellence understood as contributions to the community’s database in the form of curated annotations. Using large volumes of bibliometric data, I re-construct the mobility trajectories of Latin American zebrafish researchers (as well as of scientists from other regions) and I investigate how they relate with individual contributions and visibility within the zebrafish online database. In the final section, I provide a summary of the chapter’s conclusions.

**Mobility and research excellence: a view from the periphery**

The concepts of ‘scientific mobility’ and ‘highly skilled migration’ are often used interchangeably. Although this shows the relevance of scientific mobility as a research topic for migration, economics and policy studies (and thus beyond the social study of science), it is also indicative of the strong correlation between mobility and the notion of excellence that is frequently found in the study of researchers’ geographical mobility. Moreover, as noted by Ackers (2008, 413), when describing scientific mobility scholars often use a language that echoes an implicit Social Darwinism by using expressions such as ‘the brightest and the best’ (Mahroum 1998); ‘the youngest and most able’ (Salt 1997) or ‘skimming and poaching’ (Wood 2004).

Like internationalisation, excellence is a contested concept and, from an evaluative perspective, the relationship between these two terms is also questioned (see Chapter 2). On the one hand, excellence, understood as favourable research environments and institutional prestige, is commonly regarded as a key pull and push factor of scientific mobility (see Mahroum 1998; Franzoni, Scellato, and Stephan 2012; Rodrigues, Nimrichter, and Cordero 2016). Mahroum, for instance, argues that mobility and excellence are reciprocally constitutive to the extent that highly talented scientists are attracted to scientific sites which are reputed for excellence, and these in turn increase their credibility and prestige by hosting such leading scientists (see Mahroum 1999). Evidence of the impact of this perspective in policy-making are the 16 national initiatives registered by the OECD in the form of ‘centre for excellence grants for internationalisation in public research’. Among them, Chile’s Millennium Science Initiative (ICM), for example, aims to promote the development of innovative scientific and technological research in the country to reduce the ‘brain drain’, as well as attracting excellent Chilean and foreign scientists currently working in other countries to the national system of scientific-technological research (OECD 2019).
On the other hand, the connection between mobility and excellence is fuzzy. As noted by Ackers (2008), while mobility has long been associated and encouraged in academia – especially in physics and the life sciences (see Rothwell 2002; Rodrigues, Nimrichter, and Cordero 2016) – this practice has become deeply embedded in the career structures of scientists to the point at which it has become an ‘expectation’ (p.418). Ackers goes on to criticise the direct relationship between levels of internationalisation (in mobility terms) and individual excellence or quality (e.g. as number of publications and citations from an evaluative perspective). She recalls that mobility is just one way among many to achieve excellence in research and argues against Mahroum’s assertion that mobility and excellence are reciprocally constitutive by stressing that scientific mobility is shaped as much by ‘push’ factors (e.g. limited opportunity) as it is by the ‘draw’ of excellence (Ibid). As a result, Ackers does not contest the definition of excellence per se; she only calls into question its direct association with internationalisation. Moreover, it should be noted that Ackers’ arguments are based on data extracted from interviews with European researchers and oriented to evaluate European policy exclusively.

In Latin America, the challenging of the notion of excellence has long been a major topic among scholars who have been concerned with unveiling and denouncing dynamics of colonialism and dependency in scientific research (see Varsavsky 1969, 20; Herrera 1972; Fals Borda, Herrera Farfán, and López Guzmán 2014; Díaz, Texera, and Vessuri 1983; Cueto 1989). According to Fernanda Beigel (2016), recently the discussion on intellectual dependency has been revived in the concept of ‘colonialism of knowledge’, which describes a Eurocentric construction of knowledge, successfully portrayed as superior and universal. This, she argues, has led to two distinct streams of thought. One based on Alatas’ (2003) theory of academic dependency, which claims that certain scientific communities (i.e. those located in the central countries) are able to expand themselves following certain criteria of development and progress, whereas others (i.e. those located in developing countries) can only do so by mirroring such expansion with the subsequent negative effects for their own development. Overall, an international division of scientific labour sustains such dynamics of international dependency.

The second stream, of which Beigel is part, is heir to 1960s Third World regionalism and aims to dismantle the assumption that there exists an ‘original’ knowledge out there emerging in ‘pure’ fields of knowledge production free from
external interferences. Following this, Beigel (2013; 2014; 2016) developed a relational approach to the concept of academic dependency that allows her to put into question the notions of excellence and international prestige in science. Instead of considering ‘centrality’ as an equivalent of intellectual autonomy and ‘periphery’ of heteronomy, she argues that academic dependency involves an uneven structure for knowledge production and circulation. This dependency is sustained by the publication-based evaluation system that reinforces a hierarchy built on the basis of three principles: institutional development, discipline and proficiency in English (Beigel 2014, 621). This structure, she concludes, has historically been built in the central countries (in the U.S. mostly) and has defined our understanding of research excellence without the participation of the periphery.

In the following section, I discuss the notion of excellence in model organism research and I review existing approaches to study this phenomenon. Ultimately, I consider that a scientometric approach to study scientific mobility can benefit greatly from embracing a comprehensive critical perspective on the notion of research excellence. In the case of zebrafish and its diffusion in South America, this entails not only observing the interaction between the mobility patterns of individual researchers and their contributions and visibility within biomolecular databases, but also critically examining practices of data curation taking place at these knowledge cyberinfrastructures. As in previous chapters, this mixed-method approach will deliver new insights about the influence of the complex dynamics of scientific internationalisation in our understanding of the knowledge diffusion process and the concept of research excellence in model organism science.

**Excellence in model organisms science**

According to Laudel (2003), on the level of individual researchers, the term ‘scientific excellence’ can be equated to being an elite scientist, meaning: “making the most significant contributions to his or her specialty and providing an orientation for all specialty members” (p. 222). However, she warns the concept is too fuzzy to address the special role played by the elite of a scientific specialty. Therefore, to study scientific excellence, Laudel suggests that specialities should be clearly delineated, elite members must be identified and their spatial mobility properly observed. In the case of this thesis, my focus on zebrafish means that Laudel’s first recommendation has already been taken into account. However, the notion of scientific excellence in
model organism research has specific connotations that should be addressed separately.

The literature on model organism science highlights the collaborative and open nature of the research ethos associated with these type of scientific communities (R. E. Kohler 1994; Leonelli and Ankeny 2012; 2013; 2015; Ankeny and Leonelli 2011; Rosenthal and Ashburner 2002; J. P. Kim, Cho, and Ruiz Bravo 2008; Leonelli and Ankeny 2012; Oliver et al. 2016). In particular, Rosenthal and Ashburner (2002) describe how, together with centralised stock centres, online databases play a key role in spreading and sustaining the collaborative ethos of model organisms’ communities. It follows that the community ethos associated with model organism research not only defines the boundaries of what it means to conduct research on model organisms, but also what it takes to be considered an active participant in these communities. Namely, to engage in the exchange of resources and contribute to the community’s research infrastructures. As explained in Chapter 5, in the zebrafish community, this distinctive moral economy, however, does not often entail a free exchange of resources, as barriers to access fish stocks from centralised facilities often give way to informal networks of exchanges among researchers. Power dynamics present in practices of species exchange become more visible when they involve geographical distant and unequal actors. At the same time, internationalisation dynamics, with their complexities, allow South American zebrafish scientists to access these strategic resources, while challenging the description of this global community as a uniform and harmonious global ecosystem.

Besides centralised stock centres (see Chapter 5), online databases also contribute to spread and sustain the collaborative ethos of model organisms’ communities (Rosenthal and Ashburner 2002). Community databases are by definition an “information resource that is created, maintained or improved by a geographically distributed community” of which model organisms projects in biology are prototypical (Bos et al. 2007, 660; my own emphasis). The geographical component of the definition, I further argue, is important as it shows an intention to present this community databases as international and horizontal platforms governed by a positive community ethos that draws heavily from the dominant internationalisation discourse (see Chapter 2).

In the late 1990s and early 2000s, databases were thought to become a suitable alternative to traditional means of scientific communication in the life sciences (Fickett
The massive amount of information produced by the sequencing projects and the growth of model organism communities worldwide raised new challenges about the storing and organisation of large volumes of data. The structure of sequencing data – widely considered by life scientists as evidence in its raw form – rendered publications, including peer-reviewed papers and community newsletters, less useful to exchange scientific information (Leonelli and Ankeny 2012, 30). As a result, model organism databases (MODs), have been prominently integrated into laboratory work in the life sciences and they are believed to provide the impetus for diverse new science communication regimes to develop beyond the dominant medium of formal discourse in science, the journal (Hilgartner 1995). Some scholars, however, have been more cautious about the capacity of MODs to change practices and outcomes of knowledge production and argue that they do not constitute a threat to existing frameworks nor do they necessarily produce new epistemic cultures (see Hine 2006; Leonelli 2007).

Regardless of the performative nature of MODs – a point that I will address in the next section –, a major consensus among scholars working on this topic is the existence of a strong connection between the communities’ stated research ethos, its cyberinfrastructures and the notion of excellence itself. The social commitment to openness and collaboration in model organism research often translates into an expectation about the role of researchers in these communities. Consequently, active members in model organism communities are expected to provide data and perhaps even assist in the curation of MODs (Dietrich, Ankeny, and Chen 2014). This practice of developing and contributing to the community’s cyberinfrastructure not only establishes a boundary between outsiders and insiders; it also constitutes a pillar of the scientific repertoire by which relatively stable communities of researchers in the life sciences, and model organism research in particular, are created, managed and sustained in the long term (Leonelli and Ankeny 2015).

Existing approaches to study the development of model organisms’ communities have made use of scientometrics techniques to give account of the increasing trends in their research outputs. Dietrich et al. (2014), for instance, compared the publication trends of designated model organisms by the NIH against that of non-designated model organisms. Their research suggests that model organisms with successful publication records tend to share critical characteristics, such as being well-organised communities with good networks of exchange and
methods of communication, where databases are key features. However, their bibliometric analysis did not find a clear correlation between being designated a model organism by the NIH and an increasing number of publications. In this regard, Oliver and colleagues (2016) note that the quantity of literature produced using a species is just one metric for the ‘success’ of a model organism research community. Their study of curated data in the yeast database PomBase showed that raw paper counts obscure dramatic changes in publication content that do reflect ongoing trends in basic research. More precisely, their research found that the average number of gene annotations made per paper has grown from 5 to 35 and the average number of genes studied had increased to almost 10 during the period under study, hence widely surpassing the growth pace of papers.

Overall, what these studies show is that the notion of excellence in model organism research is directly connected to active contributions to international knowledge databases. So far, research on these key community cyberinfrastructures and its relationship with practices of international mobility constitutes a key gap in the literature. In light of this, I propose to study the interaction between mobility (as a measure of internationalisation) and researchers’ visibility within online databases (as a measure of excellence in model organism science) taking the zebrafish, again, as a case study. In addition, I look into practices of biological data curation and their impact on the notion of excellence in this community and I unpack dynamics of dependency and empowerment based on the experiences of South American zebrafish researchers.

**Biocuration practices in the zebrafish community**

Differences in the findings of the aforementioned studies indicate the need to consider not only publication trends in the zebrafish community, but also researchers’ contributions to online databases in the form of curated annotations. Taken together, this data can provide more detailed and granular information about researchers’ visibility within MODs. A key point of difference with previous studies, however, is that in this case I propose to look at the internationalisation dynamics of these research outputs by studying its interaction with researchers’ individual mobility trajectories. Moreover, I seek to examine the concept of research excellence and investigate the extent to which the zebrafish online database is performative and/or reflects the existing uneven structure for knowledge production and circulation. To do so, I discuss
the case of the Zebrafish Information Network (ZFIN), which serves as the database of genetic and genomic data for the zebrafish model.

**ZFIN.org: the zebrafish community’s database**

Besides the ZIRC – the Zebrafish International Resource Center –, the second infrastructure that plays a key role in maintaining the scientific value of zebrafish as a model organism is the ZFIN, an online public platform that provides a wide array of expertly curated, organised and cross-referenced zebrafish genetic and genomic data (ZFIN 2019b).

As discussed in Chapter 5, the creation of both ZIRC and ZFIN, agreed at the 1994 CSH meeting, was entrusted to Monte Westerfield who, along with Charles Kimmel, were responsible for securing George Streisinger’s legacy at the global stage in the late 1980s and early 1990s. This task became more pressing after the successful completion the Big Screens in 1996, which triggered a growth of data and zebrafish laboratories worldwide and, with it, a serious information access problem that increased the needs for an integrated database (see Westerfield et al. 1997, 477; Westerfield, Doerry, and Douglas 1999, 248). In addition to this, the ZFIN was to pursue more ambitious goals than serving just as the community’s central data repository. Among its long-term goals are included the following:

1. To maintain the definitive reference datasets of zebrafish research information.
2. To link this information extensively to corresponding data in other model organism and human datasets.
3. To facilitate the use of zebrafish as a model for human biology.
4. To support the needs of the research community by enhancing communication and cooperation (Howe et al. 2013).

ZIRC and ZFIN are sister organisations based at the University of Oregon that operate independently although they are largely interlinked and complementary: all the genetic information included in the database is extensively linked with probes and fish lines available at the ZIRC.

In terms of data sources, although ZFIN integrates information directly submitted by research laboratories, the majority of data comes from published research publications (see Ruzicka et al. 2015). Biocurators at ZFIN periodically scrape data about publications mainly from PubMed, a free search engine accessing primarily the MEDLINE database of references and abstracts on life sciences and
biomedical topics, maintained by the U.S. National Library of Medicine (NLM), at the NIH. Using an automated script, biocurators search for publications with the word 'zebrafish' in the title, abstract, or keywords of publications and import the PubMed ID, author names, title, and abstract for display. Each publication is later given a ZFIN-id that serves as the unique identifier within the ZFIN database. Because a significant number of curated publications at ZFIN are historic or come from scientific journals not indexed in PubMed, the ZFIN identifier is used as the primary publication identifier (Van Slyke et al. 2018).

The curation process continues with the indexing of publications by manually associating the genes, zebrafish lines, knockdown reagents and antibodies reported in the publication (Ruzicka et al. 2015, 2). Through this process, biocurators aim to organise the knowledge presented in the scientific literature into building block-like units known as ‘annotations’. These annotations connect genes to defined terms drawn from shared, structured, controlled vocabularies also known as ‘ontologies’ that represent a domain of knowledge (Oliver et al. 2016). In addition, in order to facilitate consistent and unambiguous annotation, curators use several ontologies, which are either imported from external sources such as the Gene Ontology or directly created by the biocurators, such as the Zebrafish Anatomy ontology (ZFA) and the Zebrafish Stage ontology (ZFS) (Van Slyke et al. 2014).

The manual curation of every publication is publically available in a custom web-based curation interface containing information about researchers’ specific contributions to zebrafish research, including:

- The genes involved in particular biological processes or molecular functions. These annotations, which follow the guidelines of the Gene Ontology Consortium (GO), include an ‘evidence code’ that describes the work or analysis upon which this association is based (e.g. mutant phenotype, direct assay, etc.).
- The genotype names, the genomic features, background, affected genes and current sources, if any.
- Fish records that provide information about the data annotated to a particular fish whose line – wild type or transgenic – is available at the ZIRC (Van Slyke et al. 2018).
These curated research items are also given unique identifiers at ZFIN. Together with raw counts of publications, they reflect researchers’ individual contributions to the zebrafish database and constitute a proxy to measure ‘research excellence’ in model organism research. Next, I describe with more detail biocuration practices at the ZFIN and I discuss the extent to which the zebrafish online database is performative (Callon 2007) and/or reflects the existing uneven structure for knowledge production and circulation in science. In particular, I focus on how these biocuration practices might affect contributions by Latin American zebrafish scientists.

**Publication curation at ZFIN: performativity and contributions from Latin America**

While the ZFIN acts as the zebrafish international knowledgebase, integrating information from a wide array of sources, the majority of data comes from scientific publications (Ruzicka et al. 2015). As noted previously, biocurators at ZFIN use an automated script to search for publications on zebrafish. I argue that this curation practice is performative – i.e. it contributes to the construction of the reality that it describes (Callon 2007) – as it determines the boundaries of zebrafish knowledge resulting from published documents indexed in mainstream bibliographic databases.

To assess its performativity, I first compare the literature coverage at ZFIN with that of major bibliographic databases. Secondly, I examine specific biocuration practices that might explain differences in the data coverage between these databases and how they also affects the contributions to the communal database coming from Latin American zebrafish researchers. In doing this, I used quantitative and qualitative information that provide a systematic overview of biocuration practices in the former case, and a more in-depth understanding of the zebrafish community in the latter case.

**Literature coverage at ZFIN**

To assess the performativity of the ZFIN, I analyse publications trends in this database and compare them with trends in other publication databases. In particular, I compare publications trends at ZFIN with those observed in the Web of Science (WoS) produced by Clarivate Analytics, Scopus produced by Elsevier and the aforementioned PubMed produced by the NLM\(^\text{17}\). To do so, I designed a search

\(^{17}\) Access to these digital archives was granted by The Centre for Science and Technology Studies (CWTS) at Leiden University.
strategy that imitates ZFIN’s search strategy, which looks for the word ‘zebrafish’ and its name variants in the title, abstract and keywords of publications published from 1996 to 2016 indexed in each database. By comparing the collection of documents resulting from the application of the same query in these four databases, I can analyse overlaps and gaps in data curation practices and observe the extent to which ZFIN’s collection of publications resembles that of existing mainstream bibliographic databases.

Zebrfish publications indexed in the three major databases (WoS, Scopus and PubMed) have a linear growth along the years (see figure 23). Publications indexed at ZFIN have also increased steadily albeit with a few clear production spikes that correlate with key dates in the history of zebrafish research. For instance, in 1996 – the year of the publication of the results from the Big Screens – ZFIN indexed more than 3 times the number of publications than any of the major bibliographic databases did that same year. This reflects the early efforts made by zebrafish biocurators to capture and visualise as much of the emerging literature on zebrafish as possible at a time when the zebrafish community was taking its first steps as an institutionalised global community (see Chapter 5). The second spike (2009) follows the findings on zinc finger nucleases (ZFNs) in 2008, which was the first demonstration of targeted gene inactivation in zebrafish and potentially opened up gene knockout technology to many more zebrafish researchers (Yannick Doyon et al. 2008; Meng et al. 2008). The third and last spike (2014) comes after the publication of the full-genome sequence by the Sanger Institute in 2013, which had a major impact on the zebrafish community and beyond (Howe et al. 2013).
In terms of coverage, the WoS database has the biggest collection of zebrafish literature with more than 35 thousand indexed publications. The ZFIN and Scopus collections include 28,838 and 27,410 publications respectively whereas PubMed index includes 24,472 documents. The analysis of publications overlaps (see tables 6 and 7 and figure 24) shows that a majority of publications indexed in the three major bibliometric databases can be found in the zebrafish database: 78% of PubMed publications have a corresponding match in the ZFIN database, followed closely by WoS and Scopus publications with 75% and 73% overlaps respectively. However, when looking at overlaps in the opposite direction (that is, how many of ZFIN publications are found in the other databases), these figures change. Overlaps with PubMed increase to 92% contrasting sharply with the smaller overlaps observed with Scopus (77%) and WoS (60%) collections.

**Table 6.** Total counts of publications in each bibliometric database

<table>
<thead>
<tr>
<th>Database</th>
<th>Pub count</th>
</tr>
</thead>
<tbody>
<tr>
<td>WoS</td>
<td>35,740</td>
</tr>
<tr>
<td>PubMed</td>
<td>24,472</td>
</tr>
<tr>
<td>Scopus</td>
<td>27,410</td>
</tr>
<tr>
<td>ZFIN</td>
<td>28,838</td>
</tr>
</tbody>
</table>
Table 7. Publication overlaps between the bibliometric databases.

<table>
<thead>
<tr>
<th>Overlaps</th>
<th>Pub count</th>
<th>% of WoS</th>
<th>% of Scopus</th>
<th>% of PubMed</th>
<th>% of ZFIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>WoS &amp; PubMed</td>
<td>23,062</td>
<td>64.53</td>
<td>-</td>
<td>94.24</td>
<td>-</td>
</tr>
<tr>
<td>WoS &amp; Scopus</td>
<td>24,586</td>
<td>68.79</td>
<td>89.70</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PubMed &amp; Scopus</td>
<td>22,619</td>
<td>-</td>
<td>82.52</td>
<td>92.43</td>
<td>-</td>
</tr>
<tr>
<td>WoS &amp; ZFIN</td>
<td>21,744</td>
<td>60.84</td>
<td>-</td>
<td>-</td>
<td>75.40</td>
</tr>
<tr>
<td>Scopus &amp; ZFIN</td>
<td>21,124</td>
<td>-</td>
<td>77.07</td>
<td>-</td>
<td>73.25</td>
</tr>
<tr>
<td>PubMed &amp; ZFIN</td>
<td>22,522</td>
<td>-</td>
<td>-</td>
<td>92.03</td>
<td>78.10</td>
</tr>
</tbody>
</table>

Figure 24. Venn Diagram of SQL query results depicting unique and overlapping publications identified in each bibliographic database.

A deeper look into biocuration practices at ZFIN

The above differences in publication coverage between the four databases can be largely explained by the fact that PubMed constitutes the main source for ZFIN biocurators and because of the wider coverage of journals beyond the life sciences in WoS and Scopus. However, they also relate to a series of indexing and biocuration practices conducted at ZFIN that ultimately influence the notion of research excellence in the zebrafish community. In particular, I discuss three biocuration practices: (1) priorities in data curation, (2) language of curation and (3) variety of curated documents.
**Priorities in data curation**

As acknowledged by zebrafish biocurators themselves (Ruzicka et al. 2015), given the growing size of the research community – which translates into an average of 1,000 papers added yearly to the database – and the relatively small size of the curation staff, some papers are prioritised for curation over others. Highest priority is given to publications with novel genes, new mutants or models of disease as well as to previously uncharacterised genes or those containing functional data (p.2). Moreover, because ZFIN – like any other model organism database – is a gene-centric resource, some publications like toxicology studies are not curated at all (see Hirschman et al. 2010, 416). This downplays the research contributions by peripheral scientific communities. In South America, many research laboratories have set up community services performing toxicology test for industry as a way to justify the impact of their research locally and as a means to procure additional funding for research (PI-Chile-1 2018, interviews with; PI-Chile-2 2018; PI-Argentina-9 2018).

**Language biases**

Indexes and annotations result from the manual curation of literature. This means that biocurators actually read back to back every publication they scrap from PubMed and the language of curated papers is predominantly English (Hirschman et al. 2010). Although this might be justified by the fact that English is the working language of the small curation staff of ZFIN, the extraction of literature from PubMed also means biocurators are affected by the language biases already present in mainstream bibliographic databases. As shown in table 8, English is by far the most common language of publications indexed in WoS and Scopus, as well as in PubMed, which constitutes the main source of publications for the ZFIN database.

To further assess how this does not capture non-English written research contributions by Latin American researchers, I performed a search using the keyword ‘zebrafish’ in two regional bibliographic databases: Redalyc and SciELO. These two databases were established with the aim of giving wider visibility to the scientific production generated in Spanish and Portuguese-speaking countries. The search returned 74 publications in Redalyc and 18 publications in SciELO written in Spanish or Portuguese, for the same period (1996-2016), many of which are open access. A quick inspection on the content of these publications further showed that a majority of these publications are related to toxicology research, which, as noted previously, is not a priority area of curation at ZFIN.
### Table 8. Languages of indexed publications at each database.

<table>
<thead>
<tr>
<th>Language</th>
<th>WoS count</th>
<th>Scopus count</th>
<th>ZFIN-PubMed count</th>
</tr>
</thead>
<tbody>
<tr>
<td>English</td>
<td>35,612 (99.64%)</td>
<td>26,887 (98.09%)</td>
<td>22,330 (99.15%)</td>
</tr>
<tr>
<td>French</td>
<td>55 (0.15%)</td>
<td>44 (0.16%)</td>
<td>23 (0.10%)</td>
</tr>
<tr>
<td>Chinese</td>
<td>18 (0.05%)</td>
<td>353 (1.30%)</td>
<td>132 (0.60%)</td>
</tr>
<tr>
<td>Japanese</td>
<td>15 (0.04%)</td>
<td>41 (0.15%)</td>
<td>20 (0.09%)</td>
</tr>
<tr>
<td>Spanish</td>
<td>12 (0.03%)</td>
<td>34 (0.12%)</td>
<td>13 (0.06%)</td>
</tr>
<tr>
<td>German</td>
<td>7 (0.02%)</td>
<td>18 (0.08%)</td>
<td>2 (0.01%)</td>
</tr>
<tr>
<td>Russian</td>
<td>6 (0.02%)</td>
<td>13 (0.05%)</td>
<td>1 (0.00%)</td>
</tr>
<tr>
<td>Polish</td>
<td>5 (0.01%)</td>
<td>8 (0.03%)</td>
<td>1 (0.00%)</td>
</tr>
<tr>
<td>Portuguese</td>
<td>4 (0.01%)</td>
<td>3 (0.01%)</td>
<td>1 (0.00%)</td>
</tr>
<tr>
<td>Romanian</td>
<td>2 (0.01%)</td>
<td>3 (0.01%)</td>
<td>1 (0.00%)</td>
</tr>
<tr>
<td>Italian</td>
<td>1 (0.00%)</td>
<td>2 (0.01%)</td>
<td>1 (0.00%)</td>
</tr>
<tr>
<td>Turkish</td>
<td>1 (0.00%)</td>
<td>2 (0.01%)</td>
<td>1 (0.00%)</td>
</tr>
<tr>
<td>Korean</td>
<td>1 (0.00%)</td>
<td>1 (0.00%)</td>
<td>1 (0.00%)</td>
</tr>
<tr>
<td>Hungarian</td>
<td>1 (0.00%)</td>
<td>1 (0.00%)</td>
<td>1 (0.00%)</td>
</tr>
</tbody>
</table>

**ZFIN’s extended curation**

A third aspect that explains differences in the overlaps between the selected databases relates to wider variety of curated documents beyond peer-reviewed publications including a large number of PhD and master theses as well as non-peer-reviewed publications containing preliminary or incomplete data (Ruzicka et al. 2015). This responds to a general goal of the ZFIN biocuration practice: to archive as much information as possible under the consideration that much of the unpublished information could be useful for either current or future research (Westerfield et al. 1997, 481).
Moreover, the zebrafish database allows contributions from external registered users who can submit a wide range of genetic and genomic information, including genetic markers, sequences, microarray data, genetic mapping, images and phenotypic descriptions of mutants linked with specimen information available at
ZIRC. Data obtained from mutagenesis screens provide a good example of such information. These screens generate a large amount of photographs and phenotypic descriptions that will almost never appear in scientific journals and therefore will not be available for the research community. Figures 25 and 26, give account of the impact of these curation practices in terms of the expanded ‘boundaries’ of zebrafish knowledge when compared with journal publications.

**Understanding practices of contribution to the ZFIN**

The above graphs cannot be fully interpreted without further understanding practices of contributions to cyberinfrastructures in the zebrafish community, especially in peripheral communities. By reviewing existing literature and presenting insights from interviews conducted with South American zebrafish researchers, in this section, I discuss power dynamics and asymmetries affecting contributions from the periphery to the zebrafish international database. In particular, focus on three aspects. I first discuss the lack of top-down support schemes to encourage submissions from Latin American researchers. Second, I discuss the prevalence of publications as the main indicator of excellence and the associated internationalisation dynamics in publishing practices. Lastly, I examine the lack of geographical decentralisation in nomenclature decision mechanisms in the zebrafish international online database.

Although the community ethos in model organism research expects scientists to be active contributors to the ‘knowledge’ infrastructures, in practice however there exist little incentives to submit data to genomic databases. More precisely, as noted by Rhee (2004, 544), because academic reward systems emphasise publications in scientific journals with high impact factor, many scientists and students do not consider active participation in community databases as part of their responsibilities as scientists. As a result, only those that have the capacity – namely a handful of laboratories developing large-scale mutant/transgenic fish resources in core countries – are responsible for the majority of direct data submissions to the community database (e.g. The Zebrafish Mutation Project (ZMP), hosted at the Sanger Institute is a clear example) (see Howe et al. 2013).

A series of top-down policy initiatives have been taken to counter this, albeit restricted to North America and Europe. In the U.S., all model organism-related research projects receiving federal funding via the NIH, must make their data publicly available in existing repositories and databases (see J. P. Kim, Cho, and Ruiz Bravo
Likewise, in the EU, all of the European Research Council (ERC) projects funded under the 2017 work program and later, participate by default in the Horizon 2020 Open Research Data (ORD) pilot, which states that all researchers must find suitable data repositories – ZFIN being one of them – to make their data publicly available (ERC-Scientific Council 2019).

Table 9. LAZEN resources and submissions to ZFIN. Line designations represent a unique institutional id assigned by ZFIN to laboratories who contributed with fish lines to the database. ‘LAZEN lab’ reflects the number of laboratories register in the regional network.

<table>
<thead>
<tr>
<th>LAZEN lab</th>
<th>Argentina</th>
<th>Brazil</th>
<th>Chile</th>
<th>Colombia</th>
<th>Ecuador</th>
<th>Mexico</th>
<th>Peru</th>
<th>Uruguay</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZFIN lab</td>
<td>12</td>
<td>16</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>ZFIN people</td>
<td>3</td>
<td>17</td>
<td>47</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>ZFIN line designations</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ZFIN fish lines</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: lazen.fcien.edu.uy and zfin.org (2019)

In Latin America, the lack of multilateral and regional funding schemes on zebrafish research like those in the U.S or Europe means that researchers are not required to share their data in international community databases. In response to this, regional meetings have been set up to provide a setting where direct contributions from Latin American scientists to the ZFIN can be enhanced and where researchers can share techniques and information. Aiming to diffuse standardised zebrafish research and foster advanced training of young scientists in the region, in some meetings of Latin American Zebrafish Network (LAZEN), organisers have extended invitations to ZFIN and ZIRC staff to deliver workshops. The goal of these invitations is to prepare students in the use of the community infrastructures, including guidelines to first register and then search for genes, mutants, transgenics, scientists and publications (see Whitlock 2014). Nevertheless, while the LAZEN network includes a wide number of registered laboratories, the number of labs registered at ZFIN is almost marginal. In terms of fish line submissions, only a handful of labs in Argentina, Brazil and Chile count with ZFIN allocated institution line designations, yet together they have only contributed with a limited number of mutant fish lines (see table 9).

At the same time, while some have called for scientific journals to make participation in community databases a prerequisite for publication as an alternative

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18 Except in national open data repositories like the National System of Genomic Data in Argentina.
means to foster direct contributions (Oliver et al. 2016), others have long noted that
the mechanisms that motivate journal submissions cannot be assumed to apply to
databases (Hilgartner 1995). In the latter view, improvements in technology have
changed the kinds and amounts of data production that count as a scientific
achievement, especially in the eyes of evaluators (Howe et al. 2013). Accordingly,
although the majority of zebrafish scientists interviewed for this project highlighted the
importance of being an active participant in the zebrafish community, when discussing
evaluation procedures by funding bodies and/or institutions, publications in
mainstream journals gain predominance over contributions to the community’s
knowledge infrastructures like ZFIN and ZIRC (interviews with PI-Uruguay-1 2018; PI-
Uruguay-2 2018; PI-Chile-1 2018; PI-Chile-2 2018; PI-Argentina-7 2018; PI-
Argentina-8 2018; PI-Argentina-9 2018).

Moreover, because in many cases access to these journals or to the resources
needed to conduct world-class research are critically dependent on association with
colleagues and laboratories from central countries, the uneven structure of knowledge
production and circulation gets further reinforced. Notice, for instance, how a
researcher discusses the factors intervening in publication practices in the region:

This is a super complex issue. Within my experience working in Europe and
here in South America, despite being the same person, with the same
capabilities and the same ideas, the result has been sharply different. That has
to do with access to resources and the technology that I was telling you before.
With my students, I always try access the best journals and if that means
delaying the investigation [i.e. to take longer], so be it. [However], in papers in
international co-authorship the chances increase notably. Many people think
that the name of a researcher from South America does not weigh as much as
a researcher from Europe. I don’t think that’s true but when you work with
someone from abroad, the chances are going to increase by a lot because
you’ll be able to work faster and what are going to do in those two years is
going to have more impact (PI-Chile-1 2018).

This is a key point affecting contributions to the zebrafish online database.
Because the majority of annotations are derived from published articles in mainstream
journals, it is expected that Latin American researchers’ contributions to the zebrafish
database reflect these internationalisation dynamics too. In addition, the lack of
access to standard zebrafish strains discussed in Chapter 5 acts as a deterrent to
contributions to the community database by researchers from Latin America.
Restrictions to the import of fishes and constraining criteria for strain approval at ZFIN translate into high budgetary efforts to maintain zebrafish lines that can reduce regional labs’ incentives to contribute with fish lines to the community.

Lastly, developing a standardised nomenclature constitutes another key biocuration practice that affects recognition and viability within and outside the model organism community. Aiming to facilitate submissions and enhance cooperation with researchers across scientific communities, agreement revolves around formats for presentation and access to the databases. These conventions are often formalised as inter-community institutions such as the aforementioned Gene Ontology Consortium (GO). As noted by Leonelli and Ankeny (2012, 32), such requirements meant enforcing not only standard terminological choices but also a language that would be comprehensible across several disciplines. In particular, database curators make critical interpretative choices when selecting bio-ontology terms that have the highest likelihood of being recognised and unambiguously interpreted by the database users. These choices, in turn, affect at a minimum the ways in which researchers learn to present their results to their peers using terms that are often used and understood only within the local contexts of those who define them.

With respect to name conventions in the ZFIN, the Nomenclature Committee (NC) plays a major role in enforcing epistemic agreements derived from the GO. Also appointed at the 1994 CSH meeting, the NC provides guidelines and advice for naming zebrafish genes and mutants submitted to the database. However, in contrast to the definition of community databases, strictly speaking, the composition of the NC does not reflect a geographically distributed community. Current and past members and contributors of the NC are mostly from North American (U.S. and Canada) and European institutions. Therefore, nomenclature agreements are decided without the participation of the peripheries thus replicating the existing decision mechanisms found in the publication-based evaluation system.

Analyzing mobility trajectories using large volumes of bibliometric data

So far, I have discussed how practices of biological data curation shape the notion of excellence in the zebrafish community at the global scale. I have shown that biocuration practices at ZFIN are performative and connected with greater internationalisation dynamics. The large majority of curations, I explained, are the
result of the manual curation of papers published in mainstream journals, which continue to be associated with research excellence and reproduce the uneven structure of knowledge production and circulation in science. Accordingly, contributions by Latin American zebrafish scientists to the community infrastructure are a reflection of their previous visibility within the global publication-based system.

In what follows I continue investigating the relationship between internationalisation and research excellence. In particular, I analyse how international mobility trajectories interact with contributions to the zebrafish online database. For that, I make use of scientific publications to first reconstruct the mobility trajectories of zebrafish researchers and then measure their individual contributions to the zebrafish database in terms of annotations curated at ZFIN.

A note on the measurement of mobility in science

Measuring scientific mobility is a highly complex and costly task. Historically, few governments have been able to systematically track the international mobility of the scientific workforce and there is virtually no data that allow for consistent comparisons of mobility patterns across countries (Franzoni, Scellato, and Stephan 2015). As noted by Appelt and colleagues (2015, 180) the vast body of empirical work on scientific mobility has relied on various types of data sources including surveys and censuses, repositories of curricula vitae or a combination thereof, making it difficult to replicate findings across studies.

Recently, the OECD has developed an indicator that tracks changes in the affiliation of scientific authors using bibliometric data and providing a cheaper and more comprehensive coverage across countries than surveys (Appelt et al. 2015, 179). However, indicator-based studies like the OECD tend to apply a brain drain/gain perspective of mobility that disregards authors’ multiple affiliations over time and thus provides a reductionist and homogeneous view on the phenomenon (Robinson-Garcia et al. 2019).

Since the development of automatic author name disambiguation techniques (see Moed, Aisati, and Plume 2013; Moed and Halevi 2014; Sugimoto et al. 2017), major bibliographic databases such as Scopus and – to a less extent – WoS now have a sizeable proportion of publications that include linkages between authors and their specific institutional affiliations. This has allowed researchers to differentiate between authors who have a single affiliation and those that had multiple institutional
affiliations over time and eventually provide a better understanding of scientific mobility (Robinson-Garcia et al. 2019, 51). I make use of these recent developments to map and analyse the mobility trajectories of individual zebrafish researchers from Latin American and other regions.

**Data collection and sampling**

An initial dataset was built comprising all the records of publications of individual zebrafish researchers indexed in Scopus. I extracted the authors’ information from the dataset I built in Chapter 6 containing ‘zebrafish’ as the subject descriptor of papers. Individual scientists were identified in that dataset using their unique author ID in Scopus, which combines all publication records from an author and his/her possible name variants. The validity of this approach has been confirmed by recent studies which have noted the use of the Scopus author ID allows conducting precise and reliable analyses (Moed, Aisati, and Plume 2013; Aman 2018).

Using this list of author IDs, I then proceeded to extract the whole record of publications of each author from CWTS’ Scopus custom XML database, including non-zebrafish related publications. In total, the mobility database contains 2,197,571 publication records. For each publication I extracted their PubMed ID – when available –, which further allowed me to cross-match the Scopus publications with those manually curated at ZFIN and obtain information on genes, genotypes and fish lines attached to each publication (i.e. curated annotations) (see figure 27).

![Figure 27. Diagram of compiled datasets using PubMed ID as the unique identifier.](image)

In terms of sampling, I selected only the first and last authors with at least two publications on zebrafish research over the reference period (1996-2016). This decision was taken for two reasons. First, during the fieldwork, I interviewed zebrafish
scientists and I asked them about the order of authors in their publications. The analysis of transcripts showed that there exist well-established authorship norms in life science research. The first author is often considered the person responsible for conducting the experiments and writing the results whereas the last position is associated with the ‘ownership’ of the research line (e.g. the laboratory director or Principal Investigators – PI). Middle positions are reserved for internal, external or honorific collaborators. Second, attending at the definition of scientific excellence made by Laudel (2003) – i.e. elite scientists who make significant contributions to his or her specialty and provide an orientation for all specialty members – would have made me focus only on the most prolific zebrafish authors. However, my goal was to avoid restricting the analysis to only elite scientists, obtaining instead the largest possible sample (this approach has also been applied in similar studies, see Appelt et al. 2015, 185).

I then classified authors according to the scientific community where they developed the bulk of their publishing careers. To identify scientific communities, I applied the same criteria I used in Chapter 6 – i.e. attending at the classification of research regions made by the International Zebrafish Society (IZFS) and considering the existence of regional collaboration networks in each community.

Moreover, to analyse centre-periphery dynamics within each region, I split larger regions into core and peripheral sub-communities where the core is responsible for more than 60% of publications produced in that region. For analytical purposes, these subdivisions are considered at the level of communities.

The six regional zebrafish communities are:

1. North America
2. LAZEN
3. EU-COST (core)
4. EU-COST (periphery)
5. Asia-Pacific (core)
6. Asia-Pacific (periphery)

Altogether, these six communities host more than 98% of the global population of zebrafish researchers who published in more than one year.
Methodology for analysing international mobility

To analyse mobility trajectories, I used the longitudinal dataset with more than 2 million publications extracted from Scopus (see figure 27). I analysed international mobility trajectories following the classification developed by Robinson-Garcia et al. (2019), which distinguishes between different types of mobility events and classes. A mobility event refers to each of the different possible permutations of international affiliation instances that a researcher can have between two points in time. The presence of specific mobility events in the profile of researchers further allows establishing different individual-level mobility classes (Ibid: p.53-54).

In their study, three types of mobility events are considered:

1. ‘Directionality’: indicates whether it is possible to reliably establish if an author has been chronologically affiliated first to his/her country of first affiliation and then to any other country, which is different from the country of origin.
2. ‘Rupture’: refers to a mobility of event where a researcher’s country at \( t_n \) \((t=0)\) are not found among the affiliations of the researcher at \( t_{n+} \).
3. ‘Origin’: refers to the researcher’s country (or countries) of origin and therefore denotes a lack of mobility.

Consequently, researchers can be classified as either ‘migrants’, ‘directional travellers’, ‘non-directional travellers’ or ‘non-mobile’:

a) **Migrant** researchers are those who display a directional mobility event and a point of rupture with their country of origin \((t=0)\) at any point in time.
b) **Directional Traveller** are those researchers who display a directionality event but no rupture throughout their publication history.
c) **Non-Directional Travellers** are those researchers who have had at least one mobility event but no directionality and no rupture with their country of origin.
d) **Not mobile** researchers are those who lack any mobility event throughout their careers (Ibid).

The first three classes refer to different types of mobility trajectories whereas the fourth denotes an absence of mobility.
Table 10. Example of a researcher’s international mobility trajectory.

<table>
<thead>
<tr>
<th>Au-id</th>
<th>pub year</th>
<th>country</th>
<th>t</th>
<th>event type</th>
<th>mobility class</th>
</tr>
</thead>
<tbody>
<tr>
<td>60001812493</td>
<td>2003</td>
<td>Argentina</td>
<td>0</td>
<td>Origin</td>
<td>Migrant</td>
</tr>
<tr>
<td>60001812493</td>
<td>2007</td>
<td>Argentina</td>
<td>4</td>
<td>Origin</td>
<td>Migrant</td>
</tr>
<tr>
<td>60001812493</td>
<td>2007</td>
<td>United Kingdom</td>
<td>4</td>
<td>Directionality</td>
<td>Migrant</td>
</tr>
<tr>
<td>60001812493</td>
<td>2007</td>
<td>Argentina</td>
<td>4</td>
<td>Origin</td>
<td>Migrant</td>
</tr>
<tr>
<td>60001812493</td>
<td>2008</td>
<td>United Kingdom</td>
<td>5</td>
<td>Rupture</td>
<td>Migrant</td>
</tr>
<tr>
<td>60001812493</td>
<td>2009</td>
<td>United Kingdom</td>
<td>6</td>
<td>Rupture</td>
<td>Migrant</td>
</tr>
<tr>
<td>60001812493</td>
<td>2010</td>
<td>United Kingdom</td>
<td>7</td>
<td>Rupture</td>
<td>Migrant</td>
</tr>
<tr>
<td>60001812493</td>
<td>2011</td>
<td>United Kingdom</td>
<td>8</td>
<td>Rupture</td>
<td>Migrant</td>
</tr>
<tr>
<td>60001812493</td>
<td>2012</td>
<td>Argentina</td>
<td>9</td>
<td>Origin</td>
<td>Migrant</td>
</tr>
</tbody>
</table>

This approach has nevertheless several shortcomings that should be clarified beforehand. In the first place, because this approach relies exclusively on publications to map researchers’ mobility, the classification of mobility is therefore dependent on scientists’ research output. Second, this method is likely to underrepresent short-term stays that do not result in a publication or which may not warrant adding an affiliation. Third, reliance on publication data limits the tracking of mobility to the level of the year, thus obscuring more high-frequency mobility events. Fourth, delays in publication also means that the observed mobility is a delayed event from the actual mobility. Lastly, data is limited to publications in indexed databases (e.g. Scopus) which underrepresent certain countries and languages (Ibid: 61).

The application of these procedures returned a final database containing 214,905 mobility events expanding from 1996 to 2016 for 7,296 unique authors (see figure 27). Although this represents only 9.41% of the total number of researchers listed in the dataset (n = 81,012), the sample is quite similar to the total number of zebrafish researchers reported by the ZFIN (2019a). Table 11 shows the size of the scientific population in each of the zebrafish communities and their distribution based on their mobility status (mobile or non-mobile).

Table 11. Number of researchers in each community and distribution by mobility status.

<table>
<thead>
<tr>
<th></th>
<th>North America</th>
<th>ASOC(^\d)</th>
<th>EU-COST (core)</th>
<th>EU-COST (periphery)</th>
<th>ASOC (periphery)</th>
<th>LAZEN</th>
</tr>
</thead>
<tbody>
<tr>
<td># first &amp; last authors</td>
<td>1,573</td>
<td>1,562</td>
<td>1,320</td>
<td>979</td>
<td>382</td>
<td>149</td>
</tr>
<tr>
<td>Non-mobile (%)</td>
<td>60.8</td>
<td>55.4</td>
<td>36.8</td>
<td>45.9</td>
<td>39.5</td>
<td>48.3</td>
</tr>
<tr>
<td>Mobile (%)</td>
<td>39.2</td>
<td>44.6</td>
<td>63.1</td>
<td>54.1</td>
<td>60.5</td>
<td>51.6</td>
</tr>
</tbody>
</table>

\(^\d\) Asia and Oceania (ASOC).
Next, I present the results of the analysis that compares the international mobility trajectories and contributions to the zebrafish online database by researchers from Latin America with that of researchers from other peripheral and core scientific communities.

**Findings**

I divide the report of findings into two sections. In the first part, I describe the mobility trajectories of LAZEN researchers and compare them with trajectories of researchers from other regions. In the second part, I examine the relationship between international mobility trajectories and researchers' visibility within the zebrafish online database – ZFIN.org – in terms of curated annotations – i.e. fish lines, genes and genotypes extracted from peer-reviewed publications.

**Description of international mobility trajectories**

Like their colleagues from other regions, Latin American zebrafish researchers experience international mobility at an early stage of their careers. In this sense, international mobility is a phenomenon that triggers more frequently among young researchers. In Latin America and the rest of scientific communities, researchers experience their first mobility event (either directionality or rupture) in the early years of their publishing careers (1-6 years), which are usually associated with a researcher's training period (see figure 28).
However, international mobility is not necessarily a common practice in all scientific communities (see figure 29). In North America and core Asia-Pacific, non-mobile researchers represent more than half of the zebrafish author population and the share of migrants and directional travellers in these communities is smaller than elsewhere. In North America, for instance, migrants and mobile researchers represent just about 18% of the zebrafish population respectively. In contrast, the percentage of
non-mobile researchers decreases in the rest of communities, most notably in the EU-COST (core) (36.8%) and peripheral Asia-Pacific (39.5%) communities. In the particular case of LAZEN, it is interesting to note that, despite being peripheral and a small scientific community, migration is not a predominant practice among zebrafish researchers. The share of non-mobile researchers in this region almost reaches 50%.

Figure 30. Migrant mobility flows between countries. A link between two countries reflects a direction between a researcher’s country of origin and his/her destination mediated by a mobility event of type ‘rupture’. The size of the edges reflects the intensity of these exchanges in terms of total number of researchers whereas the size of arrows is indicative of the balance flow. Node colours are adjusted by their in-degree centrality: bluish nodes reflect main centres of destination (receiving more migrants) while reddish nodes represent countries who have more out-migration. Network algorithm: WorldAtlas2. In-degree range: 5-74.

In terms of mobility flows between countries, the U.S. stands as the world magnet of migrant zebrafish researchers. Figure 30 shows the network of migrant displacements between countries. A link between two countries reflects a direction between a researcher’s country of origin and his/her destination mediated by a mobility event of type ‘rupture’. The size of the edges reflects the intensity of these
exchanges in terms of total number of researchers whereas the size of the arrows is indicative of the balance between outbound and inbound migration flows.

Figure 31. Mobility flows for Directional Travellers. A link between two countries reflects a direction between a researcher’s country of origin and his/her destination mediated by a mobility event of type ‘directionality’. The size of the edges reflects the intensity of these exchanges in terms of total number of researchers whereas the size of arrows is indicative of the balance flow. Node colours are adjusted by their in-degree centrality: bluish nodes reflect main centres of destination among directional travellers while reddish nodes represent countries who have more out-directional travellers. Network algorithm: WorldAtlas2. In-degree range: 5-59.

Next to the U.S., the UK, Germany, France, Canada and to a lesser extent Australia, also occupy central positions in the network and act as important training hubs for migrant scientists around the world. However, the majority of rupture flows in these countries are with the U.S. In line with this, the U.S. is also the main destination among Latin American zebrafish researchers, followed by the UK, Spain
and Germany. Regionally, Brazil is less affected by out-migration flows than its neighbours and acts as the main regional destination for Latin American researchers.

The network of mobility flows among directional travellers (figure 31) shows a similar although slightly different picture. The U.S. continues to be a main destination among those mobile researchers who do not lose ties with their respective countries of origin. In this case, however, the volume of exchanges between core countries (most notably the U.S, UK, China and Germany) is more intense than in migrant network suggesting a more dynamic and diverse pattern of mobility exchanges among the main centres of zebrafish research. Overall, peripheral countries, including countries from Latin America, have lower in-degree scores in both migrant and directional mobility networks, which indicates that they are more affected by out-flows than central countries are.

In sum, international mobility patterns among Latin American zebrafish researchers reflect a balance between non-mobile and mobile trajectories. Within the latter, there exists a similar share of researchers in the region who can be classified as migrant or directional travellers. The distinction between the two is that migrant researchers experienced at least one point of rupture with their home of origin whereas directional travellers have chronologically added international affiliations without losing ties with their countries of origin. In terms of destinations, like the majority of mobile researchers across the world, the main destinations for Latin American zebrafish researchers are the U.S in the first place, and Europe to a lesser extent.

Next, I examine the relationship between these trajectories and researchers’ contributions and visibility within the zebrafish online database.

**Researchers’ contributions to the ZFIN database**

Contributions to the zebrafish community database seem to coincide with the international mobility trajectories of researchers in each of the selected communities (see figure 32). Non-mobile researchers in North America, core Asia-Pacific and LAZEN communities are the most active contributors in terms of raw number of publications curated at ZFIN. The higher number of publications by non-mobile researchers is observed more clearly in North America. During the 2005-2010 period, non-mobile researchers were responsible for more than 90% of total number of publications authored by researchers from that community. In Europe (core and
periphery) and peripheral Asia-Pacific, migrant researchers are more active contributors to the zebrafish database than their colleagues are.

From a longitudinal perspective, a major difference between North America and the rest of the scientific communities is the number of articles published by mobile researchers during the early years of the diffusion process (figure 32). Outside North America, mobile scientists (particularly migrants) were clearly the most active contributors to the community’s database indicating a key influence of international mobility in the early diffusion of zebrafish outside North America.

Figure 32. Publications curated at ZFIN in each regional community by mobility class. The horizontal blue-dashed line indicates the 90th percentile limit of total observations (raw count of publications) in each community.

In the LAZEN community, in particular, migrant researchers are responsible for the majority of contributions to the online database during the first years of the period under study (1996-2006). As the series moves forward, however, non-mobile researchers and directional travellers seem to take on the role as leading community contributors in terms of curated publications. The increasing number of publications of these groups of researchers (probably young researchers who have not yet experienced their first mobility event) suggests a changing composition of the community and with it, a decreasing influence of internationalisation and/or migration in the latter years of the diffusion process of zebrafish in Latin America.

A different picture emerges when we look at the interaction between mobility and researchers’ contributions in terms of curated annotations (i.e. fish lines, genes
and genotypes extracted from publications themselves). Unlike raw publications, in this case mobile researchers are clearly the most active contributors to the ZFIN with the exception, again, of North America. In the LAZEN community, the influence of mobility on research excellence is clear: mobile researchers are responsible for about 85% of annotations involving Latin American scientists (see figure 33 a-c).

A further inspection at the classes of mobility trajectories intervening in this process shows that in peripheral communities – most notably, Latin America – migration and visibility within the ZFIN databases are two phenomena strongly related. Latin American migrant researchers, for instance, are responsible for more than 70% of fish lines identified by researchers from this community and they are also the most active contributors in terms of curated genes and genotypes (reaching 56% and 73% of total annotations respectively). This is a crucial aspect of the importance of internationalisation in the LAZEN region if we consider that migrant researchers represent only 26% of zebrafish researchers from this region. In peripheral Asia-Pacific, in contrast, migrant researchers represent the the largest group (41%) (figures 33 a-c).

In the core communities, the weight of migration is less acute and this clearly observed in gene annotations. Whereas in North America, core Asia-Pacific and Europe genetic contributions are equally distributed among directional travellers, migrants and non-mobile researchers, in the peripheral communities of LAZEN and Asia-Pacific, migrant researchers remain as the most active contributors.

In the case of fish line annotations, in all of the scientific communities – with the exception, once again, of North America – migrant researchers are the most active contributors to the community’s database. If directional and non-directional travellers are further considered, then the relationship between mobility and fish line contributions becomes even clearer. However, from this we cannot assert if mobility is directly related with access to research livestock. In other words, we do not know if researchers were working abroad when they got access to these fish lines.

To know if access to fish lines and mobility are related, I look at the countries of affiliation among mobile researchers, as reflected in the publications containing the aforementioned fish lines ID. Table 12 shows the top 10 countries of affiliation of mobile researchers in each of the six communities. Affiliation data were extracted from each of the publications where ZFIN biocurators manually curated fish line annotations.
Figure 33. Annotations distribution by mobility class in each scientific community (a-c).
Table 12. Top 10 countries of affiliation among mobile researchers and number of unique fish ids extracted from ZFIN-curated publications.

<table>
<thead>
<tr>
<th>North America</th>
<th></th>
<th>LAZEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
<td>country</td>
<td>fish id (#)</td>
</tr>
<tr>
<td>1</td>
<td>USA</td>
<td>13,692</td>
</tr>
<tr>
<td>2</td>
<td>DEU</td>
<td>2,391</td>
</tr>
<tr>
<td>3</td>
<td>CAN</td>
<td>806</td>
</tr>
<tr>
<td>4</td>
<td>GBR</td>
<td>520</td>
</tr>
<tr>
<td>5</td>
<td>CHN</td>
<td>395</td>
</tr>
<tr>
<td>6</td>
<td>FRA</td>
<td>141</td>
</tr>
<tr>
<td>7</td>
<td>ITA</td>
<td>137</td>
</tr>
<tr>
<td>8</td>
<td>KOR</td>
<td>133</td>
</tr>
<tr>
<td>9</td>
<td>ESP</td>
<td>85</td>
</tr>
<tr>
<td>10</td>
<td>AUS</td>
<td>84</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EU-COST (core)</th>
<th></th>
<th>EU-COST (periphery)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
<td>country</td>
<td>fish id (#)</td>
</tr>
<tr>
<td>1</td>
<td>DEU</td>
<td>4,969</td>
</tr>
<tr>
<td>2</td>
<td>USA</td>
<td>4,182</td>
</tr>
<tr>
<td>3</td>
<td>GBR</td>
<td>2,751</td>
</tr>
<tr>
<td>4</td>
<td>NLD</td>
<td>1,787</td>
</tr>
<tr>
<td>5</td>
<td>FRA</td>
<td>1,111</td>
</tr>
<tr>
<td>6</td>
<td>SGP</td>
<td>203</td>
</tr>
<tr>
<td>7</td>
<td>AUS</td>
<td>124</td>
</tr>
<tr>
<td>8</td>
<td>AUT</td>
<td>100</td>
</tr>
<tr>
<td>9</td>
<td>CHE</td>
<td>98</td>
</tr>
<tr>
<td>10</td>
<td>ESP</td>
<td>87</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Asia-Pacific (core)</th>
<th></th>
<th>Asia-Pacific (periphery)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
<td>country</td>
<td>fish id (#)</td>
</tr>
<tr>
<td>1</td>
<td>JPN</td>
<td>2,419</td>
</tr>
<tr>
<td>2</td>
<td>USA</td>
<td>1,747</td>
</tr>
<tr>
<td>3</td>
<td>DEU</td>
<td>1,667</td>
</tr>
<tr>
<td>4</td>
<td>CHN</td>
<td>1,500</td>
</tr>
<tr>
<td>5</td>
<td>AUS</td>
<td>880</td>
</tr>
<tr>
<td>6</td>
<td>TWN</td>
<td>422</td>
</tr>
<tr>
<td>7</td>
<td>KOR</td>
<td>368</td>
</tr>
<tr>
<td>8</td>
<td>GBR</td>
<td>192</td>
</tr>
<tr>
<td>9</td>
<td>NLD</td>
<td>135</td>
</tr>
<tr>
<td>10</td>
<td>NOR</td>
<td>107</td>
</tr>
</tbody>
</table>

In core communities, the first destination associated with curated fish lines is always a country of that community. In North America, researchers working under a U.S.-based affiliation authored more than 72% of fish lines produced by researchers from this community. In the core EU-COST community, even though the U.S. appears as the second most frequent affiliation, core European affiliations combined (Germany, the UK, The Netherlands and France) are responsible for more than 66% of fish lines produced by researchers from that community. In core Asia-Pacific the pattern explaining access to fish lines is more diverse. Researchers working under a Japanese affiliation are responsible for little over 24% of fish lines whereas Chinese institutions have contributed with more than 15% of fish lines authored by Asian-
Pacific researchers. However, mobility towards extra regional affiliations in the U.S. and Europe represent more than 48% of total fish lines produced by researchers from core Asia-Pacific countries.

In peripheral communities, including LAZEN, the first country is always an extra regional country. This suggests that in the periphery, access to fish lines and international mobility go hand in hand. There is however, a clear distinction between Europe, LAZEN and both Asia-Pacific communities. In peripheral Europe, even though the U.S. is the main affiliation associated with fish lines, a large majority of these (59%) are linked to a European affiliation from either core or peripheral European countries. In peripheral Asia-Pacific, 45% of fish lines authored by researchers from this community were produced when researchers were working under an extra regional affiliation (German, U.S. or British). In Latin America (i.e. LAZEN), U.S. dependency in the access to fish lines is clearer than in any other community: 40% of fish lines authored by Latin American zebrafish researchers were produced when working under a U.S. research institution. Moreover, if European institutions are considered, extra regional dependency reaches 70% of total fish lines authored by Latin American researchers. The rest of fish lines were authored when researchers were working under a Latin American institution with Chilean institutions acting as the main contributors in the region (18%) to the ZFIN database.

Overall, by examining curated annotations, these results add to studies of research excellence in model organism science based on the analysis of publication content reflecting ongoing trends in basic research (see Oliver et al. 2016). Moreover, my analysis of mobility trajectories presents a novel approach to study the relationship between internationalisation and research excellence in model organism science. Results show that international mobility and researchers’ visibility within the zebrafish database are closely related phenomena in peripheral communities like Latin America or Asia-Pacific. In particular, international mobility trajectories play a big part in facilitating Latin American researchers’ access to key zebrafish resources as reflected in the ZFIN database.

**Discussion**

In this chapter, I examined the relationship between internationalisation and research excellence in zebrafish research. First, I critically examined the concept of research excellence in the zebrafish community by reviewing the biocuration practices that take
place at the ZFIN, the online database of the zebrafish community. Second, I studied how the mobility trajectories of Latin American scientists interacted with their contributions to the community database. In both these aspects, internationalisation dynamics intervene unveiling complex processes of dependency and empowerment.

In model organisms’ research, excellence is strongly associated with active contributions to communal knowledge infrastructures, including livestock centres and online databases. The massive amount of information produced by the sequencing projects in the 1990s and the growth of model organism communities worldwide raised new challenges about the storing and organisation of large volumes of data. As a result, community databases sought to become a suitable alternative to traditional means of scientific communication – namely the scientific journal – in the life sciences. This has had further implications for the notion of research excellence in this field of research. Namely, besides defining the boundaries of what it means to conduct research on model organisms, the research ethos associated with these scientific communities also equated excellence with individual contributions to the communities’ knowledge cyberinfrastructure. Therefore, a clear difference exists between the notion of excellence as perceived inside and outside the zebrafish community. Contribution to online databases is perceived as a valuable practice for researchers in the community, but not for those outside of it who prioritise publications in mainstream international journals.

However, while MODs were originally conceived as an alternative communication regime that could expand the notion of research excellence, they have not changed existing communication and evaluation frameworks. In the case of zebrafish, the large majority of contributions to the database are the result of the manual curation of papers published in mainstream journals. Because of the inherent biases present in bibliographic databases and the lack of incentives to submit data to genomic databases, biocuration practices at ZFIN end up reproducing the existing uneven structure of knowledge diffusion and circulation.

Mobility trajectories are a key factor in boosting researchers’ contributions to the community’s database, especially among researchers from peripheral communities like Latin America. Particularly, the influence of mobility is greater with curated annotations than raw publications. Whereas non-mobile researchers are the most active contributors in terms of raw publications, internationalised researchers with experiences of geographical mobility in the U.S. and Europe are the most active
contributors to the community’s database in terms of fish lines, genes and genotypes, which reflect ongoing trends in basic research. Migrant researchers, who only represent 26% of the total number of researchers in the LAZEN community, are by far the most active contributors to the community’s database in terms of individual annotations.

Overall, because biocuration practices rely above all on peer-reviewed publications as their main source of data, contributions by Latin American researchers to the community database in terms of publications are a reflection of their previous visibility within the global publication-based system. In this sense, if we consider the mobility status (i.e. whether a research has been internationally mobile or not), mobile researchers produce, in general, a higher number of publications than non-mobile researchers. However, what these results show is that mobility, and by extension, practices of internationalisation, constitute critical mechanisms for peripheral researchers to access key research resources that are associated specifically with the notion of excellence in model organism research.
Chapter 8: Re-thinking Scientific Internationalisation

This chapter presents the reader with an overview of the findings of this thesis. I discuss my contributions to various theoretical discussions in STS including the concept of scientific internationalisation, the formation scientific communities and their research ethos, knowledge diffusion processes in science and the construction of the notion of research excellence in model organism science.

The internationalisation of science

In Chapter 2, I conducted a historical and spatial review of the evolution of the concept of internationalisation, which developed in Higher Education Studies (HES) since the 1990s. I described how definitions of internationalisation in HES underwent various phases to eventually settle as a top-down process of “infusing or embedding the international and intercultural dimension into policies and programs to ensure that the international dimension remains central, not marginal, and is sustainable” (Knight 2003, 3). I also noticed that scholarly efforts to develop a synthetic definition resulted in a positive definition of the term whereby the internationalisation of higher education was regarded as a desired outcome; as something that could and should be increasingly controlled.

Unlike HES, in science studies there has not been a collective scholarly debate about the meaning of scientific internationalisation thus far (Woldegiyorgis, Proctor, and de Wit 2018). Although the higher education literature on internationalisation overshadows both in numbers and depth that of STS, I found that internationalisation has been and continues to be a topic of interest among scholars in this field. This further took me to drew some parallels between discussions in HES and STS around the notion of internationalisation. I explained that, similar to HES, in STS (1) internationalisation is often discussed in terms of the national-international dichotomy that characterises scientific production; (2) the incidence of globalisation has also led STS scholars to view internationalisation as a process geared essentially towards improving science and technology; and (3) critical perspectives have also emerged in this field calling to review the meaning of related concepts such as ‘universal’ or ‘international’, and view them as codewords for ‘Western’ or ‘European’.

In sum, whilst not engaging with the concept directly, I noticed that STS scholars also tend to understand internationalisation as a transformative process that
brings about mostly positive changes in various aspect of science, including the training of researchers as well as in the production and diffusion of scientific knowledge.

**On dominant and peripheral discourses of internationalisation**

Following the description on the evolution of the concept, in Chapter 2 I also analysed the basis of the discourse of internationalisation in HES. I explained how the discourse that emerged in the 1990s rested on the belief that education and innovation systems should increase their international projection to cope with the challenges posed by globalisation. I further explained that despite recent efforts to widen its meaning, internationalisation continues to be framed almost exclusively in European and U.S. contexts and therefore largely ignores power dynamics attached and triggered by this phenomenon. I labelled this the ‘dominant discourse of internationalisation’, whereby internationalisation – i.e. a Global North construct – is conceived as a desired outcome and a tool to keep up with globalisation.

In such dominant discourse, different meanings of internationalisation sustained by contrasting policy rationales and objectives coexist. In Europe, the europeanisation of higher education, a distinct and more restricted form of internationalisation, was considered a key engine of European cooperation and integration (Van den Besselaar et al. 2012; de Wit 2013). In North America, in turn, the transnationalisation of higher education was regarded as a tool to increase the region’s competitiveness in the global arena by reducing state intervention in education services. However, in spite of propounding different means, higher education reform strategies in both Europe and North America since the 1990s have treated internationalisation as a goal in itself, seeking to increase the international dimension of their higher education and research systems (Botto 2016). A key consequence of this unproblematic conceptualisation, I concluded, is the frequent description of internationalisation as a *positive* transformation process and a *desired* policy outcome.

The discourse of internationalisation in science studies has many vertices. The positive conceptualisation of internationalisation can be observed, for instance, in studies confirming the positive correlation between practices of internationalisation and research impact. In the case of international collaboration, various studies have
shown that internationally co-authored papers tend to have higher citation rates than domestic papers or non-collaborative work (see Glänzel, Schubert, and Czerwon 1999; Narin, Stevens, and Whitlow 1991; M.-J. Kim 1999; Persson, Glänzel, and Danell 2004; Zhou and Leydesdorff 2006; Didegah and Thelwall 2013). Similar studies have been conducted on the relationship between international mobility and the number of publications and citations (see Hunter, Oswald, and Charlton 2009; Edler, Fier, and Grimpe 2011; Aksnes et al. 2013; Jonkers and Cruz-Castro 2013; Halevi, Moed, and Bar-Ilan 2016; Sugimoto et al. 2017; Robinson-Garcia et al. 2019).

Opposite to this, critical perspectives in STS have denounced internationalisation’s counter effects, such as the reinforcement of core-periphery dynamics bringing a more restrictive and uneven access to facilities, resources, knowledge and expertise (Leydesdorff and Wagner 2008; Kreimer and Zukerfeld 2014; Olechnicka, Ploszaj, and Celińska-Janowicz 2018; Robinson-Garcia et al. 2019; Feld and Kreimer 2019). Because of this, the use of classic internationalisation indicators such as international co-authorships, conceived by scientometrics as reciprocal relationships that contribute greatly towards scientific development, have been put into question recently, especially when regional and national contexts for interpreting such indicators are ignored (Robinson-Garcia and Ràfols 2020).

Critical perspectives on scientific internationalisation are not new. Scholars from Latin America (Sábato and Botana 1968; Varsavsky 1969; Herrera 1972) have traditionally denounced the inequalities of the international scientific system, even before the concept was introduced in HES in the 1990s. However, the works of this group of academics is rarely cited in mainstream STS literature. In Chapter 3, I discussed how Latin American thinkers in the late 1960s and 1970s identified international dependency in science and technology as one of the major obstacles in the development of the countries of the region. I explained how by standing in clear opposition to the international programs sponsored by UNESCO and the OAS, this group of STS pioneers explored, early on, the tension between the international and national dimensions of science from a socio-political perspective. Since the late 1980s, Latin American STS academics have relied on this dialectical tension to problematise the concept of internationalisation in contemporary science.

This review led to me observe that contemporary Latin American STS scholars have tended to describe internationalisation as a dilemma – i.e. ‘to internationalise or
perish’ – between the pressure to publish and obtain international recognition, and the threat of losing scientific autonomy. In the present context, which some scholars have described as dominated by the normative power of globalisation and neoliberalism (Martínez Vidal and Marí 2002), I concluded that such definition represents a problematisation of the concept of scientific internationalisation, which contrasts with the assumptions of the dominant discourse of internationalisation discussed in Chapter 2. In sum, in the social studies of science there exist both dominant and peripheral discourses on internationalisation.

Discourses of internationalisation in the life sciences

In Chapter 3, I moved on to examine the contrast between discourses of internationalisation in the life sciences. In recent years, some scholars have described profound transformations taking place in the life sciences that have taken it to become an increasingly bigger, collaborative, international, and networked field (see Vermeulen 2009; Vermeulen, Parker, and Penders 2013; Zimmerman and Nardi 2010; Parker 2010; Wright, Mulally, and Saucier 2018; Worlfe 2018). However, it is in the literature on model organisms, where one can find clear traces of the dominant vision on internationalisation. I demonstrated how studies on model organism science tend to decontextualize the research communities they study, focussing on their international projection but largely ignoring the power dynamics present in them (see R. E. E. Kohler 1994; Rhee 2004; Leonelli 2007; Leonelli and Ankeny 2012; 2013; Ankeny 2000; Ankeny and Leonelli 2011). Practices of collaboration and resource exchange (e.g. techniques, specimens and data) and the international infrastructures that support them, are common to all model organism communities, who have reportedly become models for good behaviour in science (Leonelli and Ankeny 2015; Ankeny and Leonelli 2016; N. C. Nelson 2013).

In Latin America, STS scholars have produced contrasting accounts of internationalisation dynamics in the life sciences. In Chapter 3, I also reviewed some of the most relevant works in Latin American STS that describe how modern scientific disciplines such as molecular biology and biomedicine emerged in ‘peripheral contexts’. The works of Vessuri (1983), Cueto (1989), Velho (1996), Kreimer (Kreimer 2011; Kreimer and Zabala 2006; 2007), among others, revolved around the notion of ‘peripheral science’ to analyse how world-class research on life can develop far from the centres of knowledge production and circulation alternating periods of relative autonomy and dependency.
Overall, this literature review led me to identify a gap in studies of scientific internationalisation in the life sciences in at least two aspects. First, Latin American studies have mostly focused on contextualised cases to describe how scientific knowledge is produced autonomously in spite of inadequate conditions (e.g. Chagas or high-altitude physiology). Little research has been conducted to understand how dynamics of scientific internationalisation intervene in contemporary South American life sciences – i.e. Kreimer’s work focused on the history of molecular biology in Argentina until the 1990s; Velho’s account of North-South collaborations in biological diversity research is based on a case study from the 1980s. Second, although mainstream STS – most notably the literature on model organisms – describes the transformative impact of internationalisation dynamics in the life sciences, it is essentially misleading. That is, it does not examine notions of asymmetry and dependency in practices of exchange as well as the structural configurations that determine the norms and expectations operating in these communities. This, I argued, often leads to a description of the life sciences as a *uniform* and *harmonious* international ecosystem governed by a strong collaborative ethos.

**Internationalisation from the perspective of South American life scientists**

Following the above observation, I set out to conduct an exploratory analysis of visions of internationalisation in contemporary South American life sciences. In the final part of Chapter 3, based on a series of semi-structured interviews I conducted with researchers in three South American countries (Argentina, Chile and Uruguay) and working in different disciplines (e.g. plant research, genetics, biomedicine, agriculture, etc.), I unpacked specific elements of scientific internationalisation in South American life sciences.

First, the analysis of testimonies from researchers showed that international mobility and transnational collaborative networks constitute key vehicles to access critical resources for conducting research on life as well as to circumvent the structural challenges of conducting research in peripheral contexts. Consequently, South American scientists often place internationalisation in opposition to the notion of ‘scientific autonomy’. However, scientists understand this autonomy exclusively in material terms and not in cognitive terms as often indicated in the STS literature.
Second, the previous point is largely explained by transformations taking place in the life sciences in recent decades that seem to have increased the material dependency of peripheral research groups. In particular, researchers have noted how the life sciences have increasingly transformed into a technologically-driven discipline rendering internationalisation practices critical for accessing sophisticated and expensive research infrastructures and less so for novel ideas or research agendas.

Third, practices of international collaborations and mobility not only help South American life scientist to access critical research infrastructures but also, and as a result of it, produce quality research increasing their chances of publishing in international mainstream journals. In this sense, while the notion of ‘pertinence’ – i.e. the idea that research must be anchored in national development goals – is weighted as an important aspect when assessing research projects, careers are still largely evaluated based on imported parameters that consider publication in international indexed journals as the main indicator of research excellence (see also Vessuri, Guédon, and Cetto 2013). This illustrates a tension in the definition of parameters of excellence.

These three observations allowed me to develop a contextualised definition of scientific internationalisation of South American life sciences. Namely, I defined internationalisation as a transformative and relational process driven by tensions in practices of resource exchange, knowledge diffusion and research excellence. Because these observations were mainly exploratory and described internationalisation dynamics at the surface, I concluded that more research was needed to elucidate how internationalisation dynamics intervene in contemporary South American life sciences.

**Demanding attention in its own right: internationalisation as a conceptual model of change**

When arguing that the dominant discourse of internationalisation ignores dynamics of power attached and triggered by this phenomenon, I align my argument with calls to re-think the concept of internationalisation and against those that sustain that scholarly discussions around this concept have reached maturity (Sanderson 2008; Knight 2011; de Wit 2011). My approach, in this sense, is closely related to previous analyses conducted by some academics who have described internationalisation as a process largely marked by tensions (Gornitzka, Gulbrandsen, and Trondal 2003;
These tensions, I argue, not only constitute new dimensions to consider in the definition of internationalisation but they also open new pathways for research in STS.

Tensions in internationalisation are varied and range from the antagonism between national and international dimensions of scientific practice, to the contrast between internationalisation and globalisation. In Chapter 2, I argued that such tensions are not just a key feature of internationalisation but also aspects of a fundamental dichotomy that is geared towards explaining how change comes about in science. In this sense, and following Vermeulen (2009), I called for the concept of internationalisation to be regarded as a model of transformation in the same manner that existing models of change in STS (e.g. Mode 2, Triple Helix or Big Science) have a dual function for explaining change. This led me to claim that internationalisation demands attention in its own right. I explained how, in doing so, research on scientific internationalisation could help deliver new understandings on key discussions in STS, namely (1) the formation of scientific communities and their research ethos; (2) the dispute in diffusion studies regarding the question of space; and (3) the formation of the notion of research excellence in specific fields of research.

These discussions constitute three theoretical settings where the study of internationalisation as a model of change could provide new insights. I will discuss in detail my contributions to each of them when summarising the results of the empirical chapters of this thesis, which has taken the zebrafish – a relatively novel and highly popular model organism whose growth in South America has been unprecedented – as a case study of transformative processes produced by internationalisation in the life sciences.

**The zebrafish: a ‘model’ to study internationalisation dynamics in South American life sciences**

While conducting my fieldwork in Argentina, Chile and Uruguay, I interviewed several life scientists working with different models. Among them, one which caught my interest was the zebrafish; a small freshwater fish, that made its way from the Ganges region in India to South America to become one of the fastest growing model organisms in this region in terms of research outputs.

Besides facilitating research about different aspects of biology, development and human diseases, model organisms, such as the zebrafish, have also served as
‘models’ for studying social dynamics in science. In Chapter 4, I discussed in detail the work of Kreimer on Chagas, a disease caused by a parasite, *Trypanosoma cruzi*, affecting between 18 and 25 million people in Latin America (Kreimer and Zabala 2006; 2007). Kreimer (2019) used Chagas as model to study how strategies and knowledge were constructed autonomously in this region as well as to examine the crossover between science and politics and the different ways of defining this problem (p. 12-13). For him Chagas is a model that shows clearly the tensions between an ‘internationalised’ knowledge – i.e. the molecular biology of *Trypanosoma cruzi* – that becomes autonomous – i.e. purified’ –. Similarly, the zebrafish is a model to study how complex dynamics of internationalisation intervene in contemporary South American life sciences.

What is interesting about the zebrafish is not just its unique technical characters, but also the way that narratives of internationalisation surround this model, such as the existence of cooperation networks and far-reaching communal infrastructures. Moreover, because the zebrafish is not an ‘autonomous’ model like Chagas but rather a ‘highly internationalised’ one, selecting it as a case study allowed me to develop a distinctive approach in the social study of model organisms: studying scientific internationalisation dynamics in a peripheral context like South America, but without using an exclusively ‘South American model’ such as Chagas. Consequently, I went on to argue that complex dynamics of internationalisation can (and should) be studied in fields of basic research or in models that are not necessarily connected to local circumstances such as a disease affecting rural population in endemic areas. In doing so, I aim to show the extent to which power dynamics are also present in what presumably are uniform and harmonious global research ecosystems.

In particular, by taking the zebrafish as a case study, I proposed to examine three different transformative dynamics of internationalisation:

(1) Practices of resource exchange and resource infrastructures that constitute the pillar of the zebrafish research ethos.
(2) The role of distinct spatial networks of collaboration in the diffusion of the zebrafish as a model organism among laboratories in the region.
(3) Data curation practices and mobility trajectories in the zebrafish community and their interaction with the notion of research excellence.
Internationalisation dynamics in practices of resource exchange

Like all model organisms, the zebrafish has particular experimental features that turn it into a powerful research tool (e.g. a small physical and genomic size, short breeding and life cycle, high fertility rate, etc.). However, a key aspect of the success of standardised research models such as the zebrafish is the existence of well-organised communities with good networks of exchange and methods of communication (R. E. E. Kohler 1994; Rhee 2004; Dietrich, Ankeny, and Chen 2014). Community infrastructures built to support these networks of resource exchange, such as stock centres, are thought to play a decisive role in the formation of stable scientific communities and therefore in sustaining the scientific value of organisms as research artefacts (Leonelli and Ankeny 2012; 2015).

Geography matters in model organism science. The zebrafish community, like many other model organism communities, is international in scope and involves a large number of researchers and laboratories from different parts of the world, which also have different needs and capabilities. Periphery is therefore an important aspect to consider when studying model organisms communities and their research ethos. Being located far from the community’s international resource infrastructures (i.e. stock centres) or having little or no access to centralised commercial holding systems or diffusion channels are factors that could have a decisive influence on a laboratory’s capacity from the periphery to produce research and make substantial contributions to the scientific international community.

In Chapter 5, I set out to investigate how internationalisation dynamics intervene in the construction of zebrafish as a model organism. Following the literature review conducted in Chapter 3, I began the chapter addressing the key limitation of existing STS research on model organism. Namely, its tendency to ignore internationalisation dynamics and thus 'un-problematise' the collaborative ethos of these communities.

My goal to study internationalisation dynamics in the zebrafish community were twofold. First, I wanted to investigate, from a socio-historical perspective, how various internationalisation dynamics standardised zebrafish as a genetic tool and formed the international zebrafish community and its proclaimed research ethos. Second, by focusing on the experiences of South American zebrafish researchers, I
unpacked dynamics of dependency and empowerment present in practices of resource exchange, as well as the barriers and reactions to international infrastructures built to support these exchanges. More generally, and in line with the conceptualisation of internationalisation as a model of change, my aim was to generate new understandings on knowledge construction processes and the formation of scientific communities.

**The standardisation of the zebrafish**

In contrast to other studies of the history of the zebrafish model (Grunwald and Eisen 2002; Holtzman et al. 2016; Meyers 2018; Varga 2018), I focused on the role played by internationalisation dynamics in the standardisation process of this little fish as research artefact. I identified at least two well-defined construction stages: (1) constructing zebrafish as a research tool and (2) constructing zebrafish as a scale-up genetic artefact. In each of these, internationalisation included travels, cross-border collaborations, personal networks and global historical processes. These developments, I concluded, not only contributed to shaping and determining the structure of the early international zebrafish community, but they also helped to configure its proclaimed research ethos.

The first phase of the evolution of zebrafish as a standard model is marked by the commencement of genetic research on the zebrafish thanks to research conducted by Hungarian-born U.S. scientist, George Streisinger. By consulting existing testimonies and reviews of Streisinger's work, I described how genetic research on zebrafish was made possible by the trajectory and connections of Streisinger and by the research context of the time. Streisinger’s work on zebrafish expanded for almost a decade (1973-1981) and was strongly supported by a scientific culture within the life sciences that fostered the quest for a comprehensive method that would bring together research on vertebrates and invertebrates. In molecular biology at the time, such a quest meant overcoming the 'diploidy problem'; i.e. figuring out how to propagate mutations through male and female heterozygous partners in order to dissect the process of biological development in a vertebrate, which thus far proved tedious and expensive.

In 1981, Streisinger published in *Nature* a technique to achieve unfertilised reproduction that allowed propagating mutations in a vertebrate, the zebrafish, in a more efficient and affordable way (Streisinger et al. 1981). This breakthrough made
Streisinger the first person to clone a vertebrate and turned the zebrafish into a serious candidate for large-scale standardised genetic analysis, which had already been achieved in invertebrates; namely the *Drosophila* thanks to the work conducted by Eric Wieschaus and Christiane Nüsslein-Volhard in the mid-1970s. However, the transformation of the zebrafish into a novel and attractive model was a consequence of a series of international events that unfolded over the following decade.

The second phase (1980s-mid 1990s) began with efforts to develop techniques to induce mutations in the fish and the organisation of the emerging zebrafish research community as laboratories outside the University of Oregon (where Streisinger worked) begun planning mutagenesis screens on zebrafish as well. Such efforts materialised in a series of international meetings that sought, on the one hand, to organise the international division of research labour that would require large-scale genetic analysis and, on the other hand, to secure the role of the University of Oregon as an international reference point for researchers across the world. Two groups, one located in Germany – led by Nüsslein-Volhard – and another in Boston – led by Wolfgang Driever and Mark Fishman – were responsible for conducting the very first international collaborative research on zebrafish, exchanging protocols as well as recipes for breeding fishes with a view to produce a large number of mutants (Nüsslein-Volhard 2012). The results of the ‘Big Screens’, as they came to be known, opened a vast pool of resources for laboratories worldwide to conduct related mutagenesis screens. In this way, the Big screens consolidated the representational scope of zebrafish and help regain the attention of funding agencies in a context marked by the international Human Genome Project (HGP).

At the same time, in one of the first international zebrafish meetings celebrated in Cold Spring Harbor (CSH), participants decided that the University of Oregon would host two infrastructures that were deemed key for the future of the zebrafish community: Zebrafish International Resource Center (ZIRC) and Zebrafish Information Network (ZFIN). Through these two institutions, the University of Oregon would be the worldwide recipient, curator and facilitator of zebrafish specimens and its associated data. In particular, the ZIRC gave the University of Oregon an authoritative voice in defining relevant future zebrafish research and in delineating the material conditions laboratories must comply with to access the model. To illustrate this, I reviewed existing guidelines and requirements for accessing and sending fish stocks and samples to the ZIRC.
Overall, internationalisation dynamics occupied a prominent place in the standardisation process of zebrafish that culminated with the publication of the results of the Big Screens in 1996, and the emergence of the zebrafish international community.

Practices of resource exchange in South America

Sending fish across borders poses critical logistical and administrative burdens to laboratories worldwide. By the early 2010s, pushed by the increasing competition between world regions, Europe and China established their own regional stock centres. In South America, however, the formation of a regional stock centre, as those existing in the U.S., Europe and China were considered out of reach for this region given the budgetary efforts this would have required. Instead, in December 2010 a group of Principal Investigators from Argentina, Brazil, Chile and Uruguay, decided to create the Latin American Zebrafish Network (LAZEN) with the aim of promoting resource sharing, collaborative research and diffusing zebrafish research in the region.

During my fieldwork in Argentina, Chile and Uruguay, I interviewed several zebrafish researchers including many who founded the LAZEN network. I learned how peripheral researchers, despite the existence of a strong international community with sound infrastructures, are critically dependent on informal networks of exchange to access the model. Restricted access to communal infrastructures and centralised commercial holdings paved the way to the emergence of these informal networks where not only specimens are exchanged but also knowledge and prestige.

In addition, I described how, for South American researchers, the zebrafish model transforms into a key resource allowing them to boost their scientific production, conduct first-class research and develop research niches despite working with smaller budgets and less well-equipped scientific infrastructures than their colleagues in the Global North. Additionally, I discussed how studies of model organism science tend to highlight the collaborative ethos of these communities and ignore how practices of resource exchange in an international community like the zebrafish often involve a mixture of cooperative and asymmetrical networks. That is, while these networks enclose power imbalances resulting from the social organisation of the zebrafish community and science in general, they also constitute key
mechanisms for peripheral researchers to bypass structural barriers and conduct research.

**Understanding model organisms’ research ethos through the lenses of internationalisation**

In the ‘Lords of the Fly’, Kohler (1994) describes the construction of the standard *Drosophila* as a response to the need to provide large-scale genetic mapping – which began to overtake neo-Mendelian experiments at the beginning of the 20th century – with an appropriate unit of analysis. Kohler places greater emphasis on the moral rules that defined the mutual expectations and obligations of the various participants in the production process of the *Drosophila*, which formed a system of exchange between rival laboratories. To a large extent, the ethos of sharing specimens and resources freely and unselfishly described by Kohler has become a common description of all model organism communities. Recent studies, for instance, have recognised the importance of collaboration networks in the growth and consolidation of contemporary model organism communities, extending this description to the infrastructures that support these exchanges and sustain the scientific value of models, such as stock centres and online databases (Rhee 2004; Leonelli and Ankeny 2012; Ankeny and Leonelli 2016). While today’s communities are more global, complex and institutionalised than Kohler’s early *Drosophilist* community, I argue that such descriptions still lead to a vision of model organism communities as uniform and harmonious ecosystems and constitute an example of the impact of the dominant discourse of internationalisation in STS.

In my analysis of the standardisation process of zebrafish, I placed the emphasis international travels, cross-border collaborations, personal networks and global historical processes, which played a key role in the construction of zebrafish as a viable and effective genetic model. These positive transformations coincide with our common understanding of how model organism communities and their research ethos are formed. However, I also discussed the power dynamics present in this history that determined the structure of the incipient international zebrafish community and the international division of research labour that would result from it.

More importantly, through the analysis of the experiences of South American researchers in these formal and informal networks of exchange, I demonstrated that the description of model organisms’ communities as uniform, borderless, and
harmonious ecosystems does not always sustain. In this sense, my description of practices resource exchange coincides with what Knorr-Cetina (1999, 255) calls the ‘logic of exchange’ in collaborative relationships taking place in biology whereby researchers render services for each other in exchange for other services and co-authorships. However, the South American zebrafish case demonstrates that it is not just an ‘individual ontology’ what drives this logic, but also the power structures in which these collaborative networks form; i.e. lack of access to communal infrastructures or centralised commercial holdings as well as expensive research infrastructures.

In sum, the tension between centre and periphery or the international and national dimensions of science captured in the conceptualisation of internationalisation as model of change problematizes the research ethos of model organism communities. It shows how practices of resource exchange among geographically dispersed communities are not necessarily altruistic, but rather reproductions of the power structures derived from the social organisation of scientific labour worldwide. This constitutes a more comprehensive approach to study model organism communities in STS. It brings perspectives from the periphery to the front, which Kohler himself recognised were missing in his study of the Drosophilist community (1994, 14).

The role of collaborative networks in the diffusion of the zebrafish model

The publication of the results of the Big Screens in 1996 turned the zebrafish into an attractive and powerful option for conducting genetic analysis on a vertebrate. The screens produced about 1,500 mutations in more than 400 genes, increasing the total number of mutations available at the time to over 7,000 and providing researchers across the world with a vast pool of resources to conduct and expand research on the zebrafish (Nüsslein-Volhard 2012; Meyers 2018). Since then, zebrafish research has become one of the fastest growing model organisms in terms of publications (Varshney, Sood, and Burgess 2015) and has built an active international scientific community sustained by international and regional congresses, communal research infrastructures and government bodies. In South America in particular, the growth of zebrafish research has been unprecedented, constituting an exemplary case of how
laboratories working with limited budgets and less well-developed infrastructures can develop world-class research (Allende et al. 2011; Buske 2012; Trigueiro et al. 2020).

The growth of zebrafish research developed in a context marked by the widespread increase of collaboration networks in science (Gibbons 1994; Wagner and Fukuyama 2008; Wagner and Leydesdorff 2005; Leydesdorff and Wagner 2008). Collaborations are considered one of the main drivers of knowledge diffusion in contemporary science and as such, they are thought to have played a key role in the diffusion of zebrafish as a research model. In Chapter 6, I examined the role of these collaborative networks in explaining the diffusion of zebrafish as a model organism across the world and with a specific focus on Latin America.

**Collaborative networks and the question of space in diffusion studies**

I began the chapter revisiting the discussion on knowledge diffusion laid out in Chapter 3. By conducting a comprehensive literature review, I found that a key aspect of contemporary diffusion studies is the confrontation between two models, one emphasising the relevance of ‘global pipelines’ to access novel ideas, and another stressing the importance of ‘local networks’ in fostering innovative development in science (see Storper and Venables 2004; Bathelt, Malmberg, and Maskell 2004; De Noni, Ganzaroli, and Orsi 2017; Torre and Rallet 2005; Olechnicka, Ploszaj, and Celińska-Janowicz 2018, 130). Such debate, I further explained, was preceded by a critique to collaboration studies put forward by some scholars who noted that the growth of collaborative research had not translated into a more equitable distribution of scientific competence but quite the opposite, to its concentration (Schott 1991; Gibbons et al. 1994; Olechnicka, Ploszaj, and Celińska-Janowicz 2018). The question I addressed in the chapter, therefore, was to understand whether zebrafish knowledge was geographically concentrated and whether collaborative networks helped diffusing it.

I also discussed the concept of ‘exposure’, which is a central feature across competing theoretical approaches in diffusion studies. I explained that diffusionist approaches are based on a linear model that allow them to identify the places where novel ideas and scientific innovations originate, to then track their diffusion elsewhere. In contrast, ‘circulationist’ approaches regard knowledge diffusion processes as a multidirectional phenomenon where scientific objects are not diffused from active innovators to passive recipients, but are rather transformed by all intervening actors.
This opposition, I argued, is mostly dialectical as the line separating both schemes is less clear in practice. To illustrate this, and following Harding (2016), I discussed the intellectual conundrum faced by Latin American postcolonial researchers for whom the rejection of the diffusionist hypothesis and the focus on the coproduction of knowledge run in parallel with a moral need to continue denouncing the persistence of hierarchical and asymmetrical relationships in science. Recently, however, diffusionist scholars have welcomed a more dynamic conceptualisation of the notion of exposure that places emphasis on social connections, helping to bring both positions together for empirical analysis. This led me to define a new diffusion hypothesis that pays greater attention to the role of social networks and the power dynamics of space:

Scientific knowledge diffuses progressively across space through a series of networks thus exposing and bringing together an increasingly wider number of spatially distant actors.

I argued that this hypothesis could be applied to study the diffusion of the zebrafish as model organism since 1996 – that is, since the publication of the results of the Big Screens – in order to understand the role of collaboration networks in this process.

**Diffusion Network Analysis: a methodology based on bibliometric data**

Following my revision of the diffusion debate, I realised that a key challenge was finding a way to study the influence of geographical collaborative networks on the diffusion of zebrafish. Accordingly, I drew on recent developments in network diffusion research to develop a methodology for studying the role of geographical collaborative networks in the diffusion of zebrafish as a model organism using bibliometric data.

Based on all the publications related to zebrafish research indexed in Scopus from 1996 to 2016, I built co-authorship networks at the level of research centres. Using techniques from Social Network Analyses (SNA), I first analysed the evolution of the global zebrafish collaborative network, focusing on the geographical configuration of the network.

Second, using techniques from Diffusion of Innovation Theory (DIT), I calculated the network exposure scores of every research centre of the global zebrafish network, meaning the proportion of collaborators in each of their networks with previous experience in the use of the model. I then calculated spatially sensitive
measures of network exposure, by using the institutional addresses indicated in the scientific publications and partitioning the networks into different geographical networks of collaborators (e.g. national, regional and international).

Lastly, using these metrics, I built a longitudinal database, which I used to model diffusion process of zebrafish across time. My motivation for designing such a model was to understand how the different spatial collaborative networks influenced adoption behaviour of research institutes in Latin America and in other communities (e.g. North America, Europe, and Asia-Pacific).

The zebrafish diffusion network

In my analysis, I described how the global zebrafish co-authorship network displayed a clear geographical clustering pattern, which became stronger across time. In addition, by analysing measures of weighted centrality within scientific communities, I described patterns of centre-periphery in the global network, with most central players located in the U.S and Europe, many of whom participated in the Big Screens experiments. Results from this inspection of the network validated the approach to study knowledge diffusion processes in zebrafish research by means of statistical modelling as a next step.

The results of the model showed that networks play an important role in the diffusion of zebrafish as a model organism. The most explicative nodes of the decision tree analysis include a combination of variables, where exposure to national networks of collaborators acted as the main explicative factor, followed by the fixed effects of time and exposure to other geographical networks. In the LAZEN region, as well as in other peripheral communities where the pace of diffusion has been slower (e.g. Asia-Pacific and peripheral EU-COST), the effects of national network exposure and fixed effects of time were accompanied by exposure to a relevant proportion of international experienced users (more than 50%). Though this might indicate that international network exposure has a bigger influence in peripheral communities, I did not find evidence of the existence of a clear pattern of international dependency in this process explained by a geographical concentration of scientific expertise in the zebrafish collaboration network.

In light of these results, I became increasingly intrigued about the significance of such networks for zebrafish researchers in South America. Through a qualitative analysis of interviews, I observed that exposure to networks of international
collaborators has less to do with exposure to novel ideas and more with access to privileged material infrastructures. This finding greatly coincides with the conclusions of the introductory analysis I developed in Chapter 3. There I described how the transformation of the life sciences into a more technology-dependent research field made South American researchers become critically dependent on internationalisation practices, such as forging collaborative relationships with colleagues in the U.S and Europe to access costly and sophisticated research infrastructures. Hence, in the diffusion of zebrafish in South America, I concluded that international collaboration constitutes a practice of approximation to more advantageous material structures, and not geographically concentrated knowledge.

**Social networks and knowledge diffusion**

Results obtained in Chapter 6 present various contributions to discussions about the role and meaning of collaborative networks in contemporary science, the relative importance of the geographical location of partners as drivers of diffusion, and methodologies for studying diffusion processes. First, the analysis of collaborative networks in zebrafish research contribute to better characterise the so-called ‘collaborative turn’ in contemporary science (see Price 1963; Cronin 2001; Leydesdorff and Wagner 2008; J. Adams 2013). The rise of international collaboration triggered by globalisation (e.g. measured in the increase of international co-authorships) is indeed a clear indication of the importance these networks for knowledge production and diffusion. Nevertheless, the mechanisms by which these international networks are sustained are not just explained by an ever-greater scientific collaborative ethos (see Gibbons et al. 1994; Wagner and Leydesdorff 2005). It is true that in some cases, the uniqueness of research renders international scientific collaboration into a necessity (astronomy or climate change research are key examples). However, in others (i.e. zebrafish case), it is rather the unequal distribution of material structures and resources that explains the important role played by these networks in the periphery.

The concept of ‘preferential attachment’ mechanism used by Wagner and Leydesdorff (2009) to described international collaboration networks in science comes to mind in this regard. According to this thesis, the formation of international collaboration networks is explained by the search for visibility, reputation, complementary capacities, and/or access to resources. At least three findings of my research point to this direction: (1) the process of transformation of the life sciences
into a more technologically driven field; (2) the relative importance of national networks *vis á vis* international networks; and (3) the testimonies from South American zebrafish researchers confirming the importance of international networks to access limited resources and costly infrastructures rather than concentrated knowledge. Moreover, my findings also coincide with the analysis conducted by Olechnicka and colleagues (2018) on the spatial patterns of scientific collaboration. Their study found dynamics of research internationalisation to be unevenly distributed and accompanied by a functional dimension for establishing a global scientific hierarchy. In this sense, my zebrafish case constitutes a detailed study of such geography of science sustained by both large-scale and in-depth evidence.

Second, the results obtained in Chapter 6 shed some light on the question of spatial proximity of collaborators and its importance as drivers of diffusion. To some extent, the findings of my diffusion model seem to reject the validity of linear diffusionist explanations depicting a geographical concentration of novel ideas and innovations, and the importance of international networks for knowledge diffusion into the periphery. I was expecting to find evidence that showed how international linkages were largely responsible for the introduction of zebrafish as a model organism in Latin America. Instead, these results, together with the insights extracted from the interviews, confront the idea that collaborative networks – even less so international networks – are influential mechanisms of knowledge diffusion. Here it should be noted that the modelling techniques I applied are based on epidemiological network models, which do not necessarily help to understand diffusion processes in science based on collaboration networks. After all, more than half of the research institutes included in the model were not classified as users. As I discussed in the chapter, these aspects refer to the limitations of the model and the choices I made to build the model.

At the same time, my analysis of interviews showed the prevalence of international power structures in the diffusion process. I reckon that such findings contribute to understanding some (and not all) aspects of the spatial mechanisms surrounding knowledge diffusion. In this sense, my findings reaffirm the intellectual conundrum of Latin American postcolonial studies as described by Harding (2016); i.e. insisting on the coproduction of scientific knowledge while denouncing the persistence of hierarchical and asymmetrical relationships in science. I argue, nevertheless, that while linearity might not constitute an adequate model to explain knowledge flows in contemporary science, it remains a valid concept for explaining
structural dependencies. This is particularly true when one considers the concentration in the Global North of increasingly more complex and expensive infrastructures to conduct research on life.

Third, the methodology I developed and explained in Chapter 6 provides researchers with a novel approach to compute spatially bounded network exposures based on affiliation data. The methodology allows researchers to study the extent to which exposure to different geographical collaborative networks explains adoption behaviour in diffusion processes. This methodology adds to network diffusion studies that consider social networks as the means by which ideas, knowledge or innovations spread across and within communities (Valente and Rogers 1995; Valente 1996; 2005). Physical space is a missing dimension of network diffusion models that take the notion of network exposure (i.e. the proportion or number of contacts in an actor’s individual network) to study diffusion processes at the micro level. Inspired by wider discussions of knowledge diffusion, the growth of collaborative networks and the hierarchical structure of science (Basalla 1967; Anderson and Adams 2008; Leydesdorff and Wagner 2008; Olechnicka, Płoszaj, and Celińska-Janowicz 2018), I argued that the geographical location of these contacts matters and should be studied.

With that said, a key limitation of this methodology – besides the technical limitations that involve modelling – is its restricted application to meso levels of analyses. In this sense, it can be correctly argued that diffusion processes present different characters depending on the level of analysis. For instance, an analysis at the micro level could reveal that the relative importance of local and global networks differ substantially from my findings at the level of research centres. The existence of authors’ multiple-affiliations over time certainly constitute a challenge for conducting this type of analysis at the micro level, using bibliometric data. Nevertheless, there are other mechanisms by which the spatial dimension can be studied at the micro level; a major one being researchers’ mobility. Though in Chapter 7 I conducted an analysis of international mobility, I leave for future research the possibility to conduct an analysis of individual mobility trajectories in knowledge diffusion. Such analysis would help to understand the extent to which research agendas were affected by experiences of international mobility and how zebrafish research was introduced in specific research institutes in South America.
Internationalisation and research excellence

In Chapter 7, I looked at the relationship between internationalisation and research excellence. In the model organism world, research excellence is defined as making active contributions to the communities’ knowledge infrastructures such as livestock centres and online databases (Leonelli and Ankeny 2012; 2015; Oliver et al. 2016). However, though there exist plenty of studies examining the relationship between scientific excellence and internationalisation (see Narin, Stevens, and Whitlow 1991; Glänzel, Schubert, and Czerwon 1999; Persson, Glänzel, and Danell 2004; Ackers 2008; Boekholt et al. 2009; Edler, Fier, and Grimpe 2011; Didegah and Thelwall 2013), I noticed that we still have little understanding of how notions of research excellence are connected with internationalisation dynamics in the life sciences, and particularly in model organism science.

In the last empirical chapter of the thesis, I analysed the relationship between internationalisation and research excellence in two key aspects of zebrafish research. First, I discussed how practices of biological data curation developed in the Zebrafish Information Network (ZFIN) – the zebrafish online database – shape the notion of research excellence in this community at a global scale. Second, I studied how international mobility – understood as a measure of scientific internationalisation – interacts with researchers’ individual contribution and visibility within the zebrafish knowledge cyberinfrastructure. As in Chapters 5 and 6, I also focused on the experiences of South American zebrafish researchers collected through semi-structured interviews with the aim of unpacking dynamics of dependency and empowerment present in these practices.

Biocuration practices in the zebrafish community

The success of the Big Screens prompted the need to count with an integrated database to collect, curate and disseminate zebrafish research across the world. The massive growth of data and laboratories worldwide that followed the publication of the Big Screen results justified the construction of an online knowledge infrastructure at the service of the emerging global community.

By describing in detail curation practices at ZFIN, I demonstrated that the zebrafish database reproduces the uneven structure of knowledge diffusion and circulation in science. I found publication scrapping techniques at ZFIN to be performative (Callon 2007) in as much they determine the boundaries of zebrafish
knowledge resulting from published documents indexed in mainstream bibliographic databases exclusively. To further illustrate this, I designed a search query that imitates ZFIN’s automated search strategy and applied it to three major bibliometric databases: Web of Science, Scopus and PubMed. I compared the collection of documents resulting from the application of the same query in these four databases and I analysed overlaps and gaps in data curation practices to determine the extent to which ZFIN’s collection of publications resembles that of existing mainstream bibliographic databases. In general, I found that ZFIN’s collection reflects mainstream indexing patterns as the large majority of zebrafish publications in the three major bibliographic databases, particularly PubMed, are present in the zebrafish-curated database.

Moreover, I found that while smaller overlaps with Scopus and WoS are due to the larger coverage of these two databases, differences can also be explained by examining specific biocuration practices taking place at ZFIN. This analysis produced several findings. First, because of the large amount of existing literature and its constant growth every year, ZFIN biocurators prioritise publications containing novel genes, new mutants or disease models (Ruzicka et al. 2015). However, and based on the testimonies of various researchers, toxicology research is a common service provided by South American zebrafish laboratories as a means to procure additional funding for research and justly the local relevance of their research. Because the ZFIN is a gene-centric resource database, scientific contributions resulting from these services (e.g. toxicology tests) are not part of the ZFIN knowledge database, which in turn reduces the prospects of greater visibility within the community’s online database.

Second, indexes and annotations result from the manual curation of literature performed by the small curation staff of ZFIN whose working language is English. This means that contributions in other languages are less likely to be picked up by zebrafish curators. Nevertheless, the extraction of literature from PubMed also means biocurators are previously constrained by the language biases already present in mainstream bibliographic databases. To assess this, I compared the distribution of publications languages at ZFIN with that of WoS and Scopus, which confirmed the predominance of English written publications in ZFIN’s curated collection. To further show how biocuration practices obscure non-English written contributions, I conducted an additional search of zebrafish publications in two Ibero-American
databases, Redalyc and SciELO, where I found a greater number of publications in Spanish and Portuguese on zebrafish, which are not part of ZFIN’s collection.

Third, extended curation practices taking place at ZFIN show how the zebrafish collection includes an impressive amount of documents beyond peer-reviewed publications, such as PhD and Master thesis, as well as a vast amount of genomic information. In particular, images and phenotypic descriptions obtained from mutagenesis screens, which are usually not part of journal publications, constitute the largest group of curated data. These images, together with fish lines and specimens, are the items most frequently associated with what the zebrafish community understands as ‘active contributions to knowledge infrastructures’, i.e. research excellence. In this sense, researchers from peripheral communities, including South America, are poor contributors compared to their colleagues from North America, Europe and China. A couple factors explain this. On the one hand, I noticed that the lack of top-down support schemes to encourage submissions is related to the limited account of contributions done by South American laboratories. On the other hand, discussions with South American zebrafish researchers revealed how the prevalence of publications as the main indicator of excellence in local evaluation practices leaves little room for contributions in other formats. Altogether, I concluded that (international) biocuration and (local) evaluation practices reinforce the uneven structure of knowledge production and circulation in zebrafish research.

**International mobility and research excellence in model organism science**

The social commitment to openness and collaboration in model organism research translates into an expectation about the role of researchers in these communities. Particularly, modellers are expected to actively contribute to model organism databases (MODs) by providing data and perhaps even assist in its curation. This practice therefore is intrinsically connected with the notion of scientific excellence and is considered a key pillar explaining the long-term sustainability of these communities (Dietrich, Ankeny, and Chen 2014; Leonelli and Ankeny 2015).

The connection between research excellence and internationalisation is a widely addressed topic in HES and STS (see Mahroum 1998; Ackers 2008; Franzoni, Scellato, and Stephan 2012; Rodrigues, Nimrichter, and Cordero 2016). In the case of model organisms, some studies have examined publication trends in well-
organised communities and have confirmed that scientometric counts tend to obscure contributions in other formats such as gene annotations, which reflect more accurately ongoing trends in basic research (Dietrich, Ankeny, and Chen 2014; Oliver et al. 2016). In light of this, in the second part of Chapter 7, I set out to examine the relationship between internationalisation and contributions to cyberinfrastructures in the form of curated annotations. Particularly, I looked at the interaction between mobility (as a measure of internationalisation) and researchers’ visibility within the ZFIN database (as a measure of excellence in zebrafish research).

**Measuring researchers’ mobility trajectories**

Measuring mobility is a complicated and sometimes even costly task. In general, there exist great difficulties to collect, analyse and compare data on the international mobility of scientific workforce (Appelt et al. 2015). However, since the development of automatic author names disambiguation techniques, bibliometric databases have emerged to become an alternative source of data for tracking scientific mobility. By examining the linkages between authors and their stated affiliations in the publications, individual mobility trajectories can be reconstructed in an effective and systematic manner.

Inspired by these recent developments, I built a large dataset comprising the full list of publication records – extracted from Scopus – of all scientists that conducted research on zebrafish. I collected more than 2 million documents and I reconstructed the international mobility trajectories of more than 7,000 zebrafish researchers following the methodology developed by Robinson-Garcia and colleagues (2019). This method provides a classification of mobility trajectories based on individual-level mobility classes that helps grasping the diversity of mobility experiences, rather than just considering mobility as brain drain/gain phenomenon. Specifically, their proposed taxonomy distinguishes between:

- **Non-mobile researchers**: those that do not experience any mobility event throughout their careers.
- **Migrants**: those that at one point in their careers interrupted links with their countries of origin.
- **Directional travellers**: those that do not break ties with their countries of origin and add affiliations as they travel abroad.
• **Non-directional travellers:** those that have more than one country of origin and therefore is not possible to establish a directionality in their mobility trajectories.

In addition to this, I extracted from the zebrafish publications their PubMed ID. This allowed me to cross-match these publications with those manually curated at the ZFIN database and obtain information on genes, genotypes and fish lines attached to each publication (i.e. curated annotations). Therefore, while analysing mobility trajectories I was also able to observe how this internationalisation practice interacted with researchers’ visibility within the zebrafish online database.

**International mobility: a booster of scientific excellence in zebrafish research**

I described the mobility trajectories of zebrafish researchers from the LAZEN region (including Argentina, Brazil, Chile, Colombia, Mexico, Peru and Uruguay) and I compared them with the trajectories of zebrafish researchers from other regional communities. In general, I found that international mobility is more frequent in the early stages of researchers’ careers. However, mobility is not necessarily a common practice across all zebrafish communities. For instance, researchers from North America as well as from countries in the Asia-Pacific region are less likely to move abroad whereas mobility is clearly a common practice among Europeans — e.g. mobile researchers represent more than half of the zebrafish author population in this region. In the LAZEN region, however, mobile and non-mobile researchers are almost equally represented, and despite being the smallest community of the six, migrant researchers represent about 26% of the total Latin American zebrafish research workforce.

My analysis of mobility flows among countries further showed that the U.S. acts as the world magnet of migrant zebrafish researchers, holding the vast majority of in-coming migrants and directional travellers. The U.S. also stands as the main destination of researchers from the LAZEN region. In terms of mobility exchanges, the majority of these take place between core countries such as the U.S., China, Germany, the UK, France and Canada.

Contributions to the community database also seem to coincide with the mobility trajectories of zebrafish researchers. Non-mobile researchers in North America and in core countries from the Asia-Pacific region are the most active
contributors in terms of raw counts of publications curated at ZFIN. When analysed from a longitudinal perspective, however, I found that migrant researchers were the most active contributors to the community database during the early years of zebrafish research, with the exception of scientists from North America. This shows the key influence of international mobility outside North America, a practice that nevertheless has tended to decrease across years.

However, when I looked at the interaction between mobility and researchers’ contributions in terms of curated annotations (e.g. genes, phenotypes and fish lines), this pattern changes. Unlike the case of raw publications counts, mobile researchers were clearly the most active contributors to the ZFIN with the exception, again, of North America. In the particular case of researchers from the LAZEN countries, the influence of mobility on research excellence is clear: mobile researchers are responsible for about 85% of annotations involving Latin American scientists, which confirms the role of international mobility as a booster of research excellence, especially for researchers in the periphery. Moreover, international mobility constitutes a key practice for accessing fish stocks: 70% of fish lines authored by LAZEN researchers were produced when Latin American researchers were working abroad; mostly in the U.S and in core European countries.

Overall, I found mobility to be closely related with an increasing visibility with the community database in peripheral communities such as LAZEN or Asia-Pacific. Migrant researchers from peripheral communities are responsible for the majority of curated annotations coming from these regions. I therefore for concluded that international mobility is a critical mechanism for peripheral researchers to access key resources directly associated with the notion of research excellence in the zebrafish community.

**Internationalisation, excellence and model organisms**

The findings reported in Chapter 7 add to ongoing discussions about internationalisation, research excellence and model organisms in at least two ways. On the one hand, my analysis of biocuration practices at ZFIN describe the mechanisms that shape the notion of research excellence in model organism science, a topic that has received little attention thus far. I demonstrated that structural asymmetries and hierarchies of scientific research are present in practices of resource exchange and in infrastructures frequently described as horizontal, collaborative,
international and accessible (see Bos et al. 2007; Leonelli and Ankeny 2012; Oliver et al. 2016). Next to resource centres, MODs are a key information resource that contribute to spread and sustain the scientific value of model organisms and the collaborative ethos their research communities (Rosenthal and Ashburner 2002). The massive growth of information produced by the sequencing projects in the late 1990s and early 2000s and the structure of this new type of information – largely considered as evidence in its raw form in the life sciences – further increased the value of MODs as a new form of communication regime in detriment of peer-reviewed publications (Fickett 1989; Gilbert 1991; Leonelli and Ankeny 2012).

While it is true that the massive amount of information stored in these cyberinfrastructures is of great value for researchers to the point that they have been prominently integrated into laboratory work, they are still far from displacing the traditional peer-review system as the basis upon which the notion of research excellence is built in these communities (Hilgartner 1995). My analysis of biocuration practices at ZFIN as well as evaluation practices in South American countries provide empirical support to observations made by existing studies which have been more cautious about the capacity of MODs to change practices and outcomes of knowledge production and produce new epistemic cultures in model organism research (see Hine 2006; Leonelli 2007). Moreover, these findings allow us to understand the mechanisms responsible for constructing the notion of excellence and international prestige in science described by Beigel (2016), which systematically exclude the periphery. Instead of considering ‘centrality’ as an equivalent of intellectual autonomy and ‘periphery’ of heteronomy, Beigel claims that academic dependency involves an uneven structure for knowledge production and circulation sustained by the publication-based evaluation system. Biocuration practices at ZFIN, in this sense, are a concrete example of the mechanisms theorised by Beigel. That is, the (in)visibility of South American zebrafish researchers in the community database is a reflection of their previous (in)visibility within the global publication-based system.

On the other hand, my analysis of curated annotations and international mobility trajectories constitutes a novel approach to study the development of model organisms’ communities from a quantitative perspective. Thus far, existing studies have examined trends in counts of publications as well as gene annotations to assess the extent to which these communities grow and stabilise over time (Dietrich, Ankeny, and Chen 2014; Oliver et al. 2016). The study conducted by Dietrich et al (2014),
which compared publication trends of NIH designated model organisms and non-designated model organisms, found no correlation in this designation and concluded that the existence of good networks of exchange is a potential explanatory factor of the success of NIH-designated organisms. In turn, I examined how international mobility trajectories interact with these types of research outputs as an alternative way to examine the relationship between the notions of internationalisation and research excellence. Mobility is a relevant topic to consider in the social study of model organisms science because it provides another layer of analysis of the social practices and spatial dynamics that contribute to the ‘success’ of these communities. The physical mobility of Latin American zebrafish researchers, for instance, allow them to access resources that are unevenly distributed globally (including both species and research infrastructures). Mobility trajectories therefore play an important role as drivers of knowledge diffusion and in forging the networks of exchange frequently mentioned in social studies on model organisms.

**Moving forward**

In this chapter, I presented an overview of the findings of the thesis. I discussed my contributions to various theoretical discussions, including the concept of internationalisation, the formation of scientific communities and their research ethos, the role of space and collaboration networks in knowledge diffusion processes, and the relationship between internationalisation and the notion of research excellence in model organism science.

While summarising the conclusions of the thesis, I also started to reflect on the practical contributions of this thesis including the prospects for combining methods in STS, the conceptualisation of internationalisation as a model of change, and new pathways in the design of internationalisation policies and the future studies of internationalisation. In the next and final chapter of the thesis, I present a summary of these reflections.
Chapter 9: On to new waters…

In this final chapter, I share some reflections on aspects that go beyond the empirical findings of this thesis. It is my intention that the following discussion provides insights from various points of view – e.g. theoretical, methodological and policy-making – that contribute to further expand our understanding of scientific internationalisation. In the first section, I bring back the debate on the epistemic divide in STS and the separation between quantitative and qualitative approaches. In particular, I discuss a proposal to overcome such divide, I review the contributions of each method throughout the thesis, and I share some lessons learned from conducting a mixed-method research in STS. In the second section, I describe contributions of this thesis in terms of a shift of perspectives in two key fields: internationalisation studies and internationalisation policies.

Building a bridge between two worlds

In each of the three empirical chapters of this thesis, I followed a mixed-method approach to analyse dynamics of scientific internationalisation. The combination of methods does not just entail using different data sources and techniques of analysis. A mixed-method research design has deep and complex epistemological questions I had to address beforehand and which I continued to reflect throughout the thesis.

A brief account of the epistemic divide

In STS, mixed-method approaches are rare although increasingly more popular, and precisely the depth of these epistemological questions is the reason for their scarcity. In Chapter 4, which presents the methodology of the thesis, I attempted to tackle this challenge by discussing the implications, limitations and opportunities of combining methods in STS. Following the analysis conducted by Wyatt et al. (2015), I first described how two contradictory epistemologies have coexisted in this discipline – quantitative and qualitative STS –, each with its particular set of assumptions, units of analysis and of course, strengths and limitations. I also discussed Shrum et al. (2007) study on the structure of scientific collaborations, which is one of the most important studies in STS based on mixed-methods. Shrum and colleagues use Galison’s (1997) metaphorical contradiction between image and logic in microphysics to describe the struggle between these two epistemic traditions in STS. The image tradition – i.e. qualitative STS –, they explain, seeks to produce instances so well defined (i.e. a
‘golden event’) that could provide the basis of compelling explanations without needing to invoke further data. The logic tradition – i.e. quantitative STS – in contrast, relies on numerical and statistical demonstrations that would illustrate which events are significant and which are not. According to Shrum, in order to overcome this divide, researchers need to develop an interlanguage that would make ‘local coordination’ possible and ultimately develop a ‘hybrid’ tradition. In my view, it is not clear what the mechanisms that sustain such interlanguage are. I therefore argued that we ultimately need a deeper appreciation of what is being ‘traded’ in the attainment of such hybrid tradition.

**A proposal to overcome the divide**

I relied on recent discussions about the responsible use of scientometrics in research evaluation to further discuss the opportunities and limitations of building a bridge between both traditions. Some scholars have emphasised the importance of context when designing and using scientometric indicators for evaluation purposes, as well as the level at which we conduct our analyses (Waltman 2018; 2019; Leydesdorff 2018). According to this appreciation, quantitative analyses are suitable for conducting research at the macro level, showing patterns and large structures whereas at the micro level there exist particularities that require in-depth qualitative analysis.

I argued that there is great potential for extending this approach to science studies. I claimed that instead of developing a hybrid language, we should let each method ‘speak for itself’, and the social study of internationalisation provides a good case to apply this vision. As I explained in Chapters 2 and 3, internationalisation is a multi-level phenomenon. This means that both epistemic traditions can provide tools to examine processes at each level and fill the gaps left by the other. For instance, qualitative methods like interviews and document analysis provided in-depth insights about specific individual cases (i.e. images) that complement the logical observation of internationalisation dynamics at the macro level. Next, I provide some concrete examples.

**A mixed-method analysis of internationalisation**

In Chapter 5, quantitative analysis helped me to describe the collaboration network of the early zebrafish community by means of bibliometrics and SNA. In Chapter 6, by using one again bibliometrics and SNA techniques, I mapped the global collaboration
network of the zebrafish community and I described its spatial patterns and its evolution over a period of 20 years (1996-2016). Moreover, through advanced statistical techniques, I was able to model the diffusion of the zebrafish organism and understand the influence of distinct geographical collaboration networks in the adoption of this model in Latin American and in other regional communities. Lastly, bibliometric techniques in Chapter 7 helped me to assess the scale of biocuration practices as well as re-construct the mobility trajectory of more than 7,000 researchers (from Latin American and other regions).

In the three empirical chapters, qualitative analyses in turn provided detailed information of internationalisation practices and enabled a critical reflection of key concepts such as ‘exposure’ and ‘excellence’ in model organism science. Through document analysis and thematic analysis of interviews conducted in Chapter 5, I unpacked dynamics of dependency and empowerment in practices of resource exchange, which further allowed me to problematise the research ethos of the zebrafish community. For its part, the analysis of interviews with South American zebrafish researchers in Chapter 6, took me to inquire further about the meaning of international collaborations for researchers in the region, an aspect that the network diffusion models took for granted. Lastly, qualitative research added another layer of analysis to the notion of research excellence in model organism science, highlighting the continued reproduction of the uneven structure of knowledge diffusion and circulation in science in biocuration practices at ZFIN.

A key message of the discussion on the responsible use of scientometrics is the need to increase transparency in the use of quantitative metrics. This requires acknowledging and understanding the limitations and biases inherent to them so that they are not misinterpreted due to technical and conceptual assumptions (Waltman 2019). Accordingly, in Chapters 6 and 7, besides describing in detail the methodology for both extracting and analysing quantitative data, I also discussed critical approaches to the concepts of collaboration and research excellence, for which the metrics I used (co-authorships, international mobility and curated annotations) served as proxies.

In addition, in Chapter 6, I discussed the limitations of the statistical model I built to study the diffusion of zebrafish. In particular, I noticed that various choices inform the construction of statistical models, which can lead to different empirical results. In this case, using yearly intervals as a measure of time of adoption (TOA),
arbitrary decisions I took to define what counts as a user in this model or ignoring the
great differences that exist within scientific communities certainly had a decisive
influence on the results I obtained. Similarly, in Chapter 7, I explained that although
using bibliometrics to re-construct mobility trajectories is a powerful alternative to
more traditional and expensive methods (e.g. surveys o researcher’s CV), they
nevertheless have several limitations. Some of these include the tendency to
underrepresent short-term stays or the underrepresentation of certain countries and
languages that results from the use of publication indexed in mainstream databases
(Robinson-Garcia et al. 2019, 61).

I am aware that addressing biases of quantitative techniques or
acknowledging that insights derived from qualitative analysis cannot be generalised
to other contexts may not be sufficient conditions for overcoming the epistemic
distance between these two traditions in STS. However, I do consider that in
attempting to build a bridge between qualitative and quantitative STS, acknowledging
these limitations is a good place to start building bonds between both sides. I am also
aware that the adoption of a mixed method design entails the risk of addressing a
smaller audience as advocates of each epistemic tradition generally tend to view the
opposite method as intrinsically flawed. Qualitative researchers, for instance, may
consider bibliometrics as highly technical, complex and poorly rooted in theory. For
their part, quantitative researchers may view qualitative methods as excessively
abstract and subjective. The major evidence for the prevalence of these views is the
fact that as of today, there are few journals devoted to mixed-method research in STS.
Overcoming these differences will certainly require a change of research culture in
STS, though it is also a matter of facilitating proper diffusion channels. This, I reckon,
is another place where we should start if we are serious about building a bridge
between these two worlds.

Towards a change of perspectives of internationalisation

What conclusions can be drawn from the thesis findings that contribute to generate
new perspectives for future internationalisation studies or to improve the design of
internationalisation policies? How do both the zebrafish case and the South American
context encourage a critical reflection on internationalisation in the global arena? In
what follows, I attempt to answer these questions, through which I seek to conclude
this thesis.
Internationalisation studies

In HES, discussions about internationalisation have expanded over three decades leading some scholars to claim that this debate has reached maturity (Sanderson 2008; Knight 2011; de Wit 2011). Though such claim might be contested due to the ongoing efforts to incorporate views from the Global South and recognise the power dynamics present in internationalisation processes, HES scholars have discussed the meaning of internationalisation. In contrast, as noted by Woldegiyorgi and colleagues (2018), in STS it is not yet clear what we mean when we talk about scientific internationalisation. What we have instead is a rich, albeit dispersed, body of literature that has been more inclined to describe modes and patterns of internationalisation in science, but less so on discussing its meaning. I contend that scientific internationalisation as a model of conceptual change contributes to encourage a much-needed scholarly discussion on the concept in science studies.

I recognise (or more precisely, I wish), that such claim can generate reactions that stress the theoretical and empirical limitations of internationalisation as a model of change, because such responses are the first steps towards an open discussion on the concept. The appearance of concepts like ‘post-normal science’ (Funtowicz and Ravetz 1994) and ‘Mode 2’ (Gibbons et al. 1994) prompted discussions about the new forms of knowledge production that referred to fundamental changes in the organisation of science. In the late 1990s, Peter Weingart, for instance, described how such concepts, which at the time were perceived as innovative, were in fact “as much notions motivated by ideas of a politically ‘more correct’ science as they are description of actual changes” (Weingart 1997, 592). Weingart was bitterly nostalgic about the lack of recognition of the precursor of these new concepts, ‘finalised science’ (Böhme, Van den Daele, and Krohn 1973; Schäfer 1983), which discussed how science was becoming more mission-oriented and how this had increasingly guided the development of scientific theory itself (Böhme, Van den Daele, and Krohn 1973, 307–8). Weingart’s thesis rested on the claim that descriptions of the new forms of knowledge-production pertained to a specific section of the research system (i.e. policy-related fields) and could not be generalised to science as a whole. In other words, Weingart claimed that Mode 2 and similar schemes essentially lack theoretical depth. Reading Weingart’s review has led me to consider the limitations of this thesis as well as aspects of a potential future conversation about scientific internationalisation in STS.
Limitations and future research

First, the dynamics of internationalisation I have analysed in this thesis are limited in their generalisation capacity. Rather than scientific internationalisation, what I have analysed in this thesis are internationalisation dynamics in two specific contexts: South America and model organism science. Though I tried – when possible – to draw comparisons with communities outside South America/Latin America, I did not examine international dynamics in other scientific domains. This might have revealed contrasting transformative processes in knowledge production and diffusion to those I described. Future research on internationalisation should assess whether changes induced by internationalisation across scientific fields. This will increase the theoretical depth of the concept. In any case, researchers should state not only on the methods employed in their research, but also describe the specific contexts in which they conduct their analyses. Moreover, to expand the theoretical depth of scientific internationalisation, is vital to incorporate views from outside mainstream STS (Law and Lin 2017) when we talk about scientific internationalisation.

Second, while I have stressed the importance of context for studying internationalisation as a multi-level phenomenon (i.e. spatial, historical and disciplinary contexts) I did not explore other key contextual factors such as local research cultures or gender dimensions. By adopting a Latin American or South American perspective, I assumed these are well-defined and rather homogeneous regions. Indeed, when discussing these and other regions (e.g. Europe, South-East Asia, etc.) as unified entities, I favoured structural factors over local contexts in the analysis. Future research on internationalisation therefore could investigate how local research cultures shape the notion of internationalisation. In particular, local research evaluation practices are a clear example of contextual interpretations of internationalisation practices and policies. For instance, definitions of scientific collaboration, international mobility and/or research excellence, say in Brazil may differed from those of Chile, Argentina or any other neighbouring country and therefore have distinct policy frameworks that promote such practices. Gender is another factor that this thesis overlooked. Gender is an important dimension to consider in the study of internationalisation given its strong links with the notions of power and asymmetry and its capacity to produce different interpretations and patterns of internationalisation to those commonly observed in internationalisation studies. Gender disparities in mobility trajectories or in the organisation and
distribution of credits resulting from international collaborations are key vectors of asymmetry that cut-cross disciplinary and spatial dimensions of scientific practice.

Third, internationalisation as a model of conceptual change is built on previous observations made by other schemes about the changing organisation of scientific practice: i.e. the growing importance of networks for interdisciplinary and cross-institutional research, the growth of scale of research and changes in evaluation criteria. However, the concept also covers the tensions that are present in these transformations. Internationalisation, – a fundamental, though overlooked, component of schemes like Mode 2 and the Triple Helix –, embodies tensions in various dimensions: geography, research ethos, evaluation, epistemology (see Chapter 2). This brings me to recall the conclusions of the report on internationalisation of research and higher education written by Gornitzka and colleagues (2003). The authors of the report called for future research on internationalisation to take these tensions as ‘core hypotheses’ about central aspects of current developments in the field of internationalisation of knowledge production and dissemination (Ibid, p.133). This thesis has taken on this challenge by conducting theoretical and empirical research on internationalisation from the perspective of South American life sciences. However, for reasons of time and research design, some of the tensions listed by Gornitzka and colleagues have not been addressed in this thesis, though they remain important for future research. For instance, in knowledge diffusion processes there is still much left to explore concerning the contrast between cooperation and collaboration in transnational scientific networks, or the tension between convergence and divergence in knowledge production; that is, whether internationalisation leads to more similarities between actors or to increased differentiation.

Overall, future internationalisation studies in STS should engage with the concept directly and try to answer what we mean when talk about scientific internationalisation. To open this conceptual conversation, further research is needed in the changing dynamics introduced by internationalisation in other scientific fields, communities of scientific practice and contexts. Ultimately, future research on internationalisation will contribute to problematise notions and practices of scientific research that have been taken for granted.
Internationalisation policies

Contemporary internationalisation policies are based on particular political assumptions that pursue collaboration and/or enhancements of relative capabilities in a competitive setting. The increase in global university rankings, the growth of brain gain/drain migratory flows, the predominance of English as the language of science, or the increase in the complexity and costs of research infrastructures, are often used as indicators of the ‘globalisation of science’, a concept that is based on the competition principle whereby science is perceived as a tradable commodity. In turn, the growth of long-distance collaborations measured through international co-authorships is often used as an indicator of the increasing cooperation in science (Waltman, Tijssen, and Eck 2011). However, policy-makers and research managers do not conceive the purpose of these practices of internationalisation beyond the need to produce knowledge or complement capacities between collaborating partners. In this way, the dominant discourse of internationalisation, based on a positive vision of the internationalisation of science, leaves little room for the inclusion of critical perspectives in contemporary science policy-making.

Critical perspectives in internationalisation policies

In the 1960s and 1970s, STS in Latin America began from concerns with science policy and a joint criticism of the dependencies and structural asymmetries of the emerging international scientific system of the post-war period, which had directly interfered with the development of the countries in the region. These thinkers criticised the policies and programs of international organisations such as UNESCO, ECLAC or the OAS, which from their point of view perpetuated the dependency of researchers and local research institutes with the main centres of knowledge production (i.e. US and Europe). In this sense, internationalisation practices such as international mobility and collaboration were viewed as mechanisms that preserved centre-periphery relations in science. This vision, developed by STS thinkers towards the internationalisation of science, therefore contained a strong critical component that in subsequent decades lost steam.

In the 1980s and 1990s, the decades of greatest incidence of globalisation and economic neoliberalism – which in Latin America became known as the ‘lost decades’ –, the ideas of the Latin American School of Thought in Science, Technology and Development (LASTSTD) were stigmatised and defined as ‘nostalgic thinking’
(Martínez Vidal and Marí 2002). Paradoxically, this also coincided with the beginning of discussions on internationalisation in HES in the early 1990s (see Chapter 2).

In light of the failure of the neoliberal model in the region, the ideas of the LASTSTD have regained momentum in recent years. However, on this occasion, the focus of criticism is no longer placed in the development programs sponsored by international organisations, but rather on the structures of the international research system that increase inequalities in the political, economic, socio-cultural as well as techno-scientific spheres. According to Kreimer (2006), many emergent processes – i.e. information and communication technologies and different modalities of funding research in developed countries – show a new type of international division of scientific work. In this new organisation, the freedom grades of peripheral groups in the definition of research agendas – and even in the selection of techniques – seem more constrained than in the past. Contemporary Latin American perspectives on science policy emerging from STS, have started to incorporate a similar critical stance on internationalisation that views evaluation and science policies as mechanisms that impose foreign research agendas and neglect local problems (Vessuri, Guédon, and Cetto 2013; Kreimer 2015).

The above perspective clashes with the dominant discourse of internationalisation that continues to guide the design of strategies in the Global North to improve the scientific development of the periphery. For example, as stated by Quan et al. (2019): “For developing countries, international collaborations represent an ideal opportunity to improve both scientific visibility and research impact by allowing their researchers to work with colleagues from more advanced scientific countries” (p. 708). While this may be true to some extent regarding citation impact, it is at least questionable from a knowledge production perspective. Robinson-Garcia and Rafols (2020, 216), for instance, argue that internationalisation is not an essential condition for a country’s capacity to develop scientific knowledge autonomously and independently. Based on the findings of this thesis, I argue that there is a gap between these two positions, which critical perspectives of internationalisation should take into consideration.

For instance, what happens when, in situations of uncertainty, internationalisation is in fact equivalent to autonomy, yet motivated by factors other than those outlined in the dominant discourse? The zebrafish case shows that research coming from Latin America is not driven by access to geographically
concentrated knowledge nor by a restriction in research agendas, but rather by structural factors that respond to global, local and disciplinary transformations. These include lack of access to international resource infrastructures, publishing channels, restrictions to the import of fishes or the transformation of the life sciences into a more technologically driven field. In this case, internationalisation practices are a means for producing science locally in the absence, in many cases, of internationalisation policies or programs. This explains why scientific internationalisation in South America continues to be a process that largely depends on the relational capital of researchers – as opposed to a top-down process –, and which allows them to circumvent uncertainties produced by local and global contexts.

So how can these reflections change internationalisation policies? Science, and by extension its internationalisation, are not apolitical processes, and so scientific internationalisation policies must address injustices and inequalities. It follows that evaluation should pivot to assess the extent to which cooperative networks are successful mechanisms for bringing about positive change in disadvantaged communities in a sustainable and culturally sensitive manner. In Latin America, policies should not be based on an antagonist view of internationalisation or in one that regards research as a commodity. They should ultimately aim to achieve a transformation of international links into cooperative relations that address structural asymmetries. Good examples of this include the establishment of joint international research centres or partner research institutes such as the Institute Pasteur Montevideo, affiliated to the Institut Pasteur International Network, and the Biomedicine Research Institute of Buenos Aires, Partner Institute of the Max Planck Society. Both institutes are examples of how historical cooperative relations can be geared toward enhancing local research capabilities while boosting the international profile of partners from developed countries. Notwithstanding, these cases should be studied in detail to assess the extent to which these experiences have actually led to more equality/inclusion. For its part, in the Global North this change of perspectives, should also take universities to devote efforts and resources not on climbing steps in global rankings, but rather generating cooperation policies and spaces for discussion with partners from countries of the Global South aiming to bring positive transformations in their local contexts (Gadd 2021). In doing so, internationalisation becomes a social commitment that defines the identity and global mission of research institutes and universities.
Another clear example where a shift of perspective is necessary are research infrastructures. As Van den Besselaar et al. (2012) explained, “[t]hese infrastructures play an increasingly important role because they offer research services to users from different countries, attract young people to science, and help to shape scientific communities” (p.18). In this sense, internationalisation policies should not only promote and guarantee international access to these infrastructures, but should also attempt to democratise and expand their government and technical bodies in order to produce more inclusive research. Local funding and evaluation bodies in Latin America should also encourage active participation in these infrastructures as a means to expand the notion of research excellence beyond publication in mainstream and international scientific journals.

Overall, the great challenge of future science policy is to be able to link the question of development – a key contribution of the Latin American STS tradition – with the notion of internationalisation. This means insisting, on and on, that the foundation of internationalisation policies should not be competition but cooperation with ‘transformation’ purpose. That is, internationalisation policies should aim to reduce asymmetries and injustices in the international scientific system.

**Internationalisation policies and the rise of nationalism**

Nationalism and internationalisation are not opposite poles. The relationship between these two concepts is both dialectical and paradoxical. As noted by Goldman (2001), while internationalisation implies the existence of nation-states, studying internationalisation is exploring a process where “distinctive units lose their distinctiveness” (p.9). Internationalisation policies do not scape this puzzle. Thought internationalisation strategies ultimately seek to enhance national scientific capabilities, they do this by promoting the global exchange of ideas, resources and people, through which national boundaries become blurred.

Like internationalisation, nationalism is a contextual phenomenon. In Latin America, nationalist and populist movements have been historically conceived as political forces that promote development and social inclusion, and which denounce global inequalities and injustices. The more recent example of the integration of nationalist agendas in Latin American internationalisation policies is the inclusion of mandatory return clauses in programmes of international mobility. These mechanisms have been adopted to assure the return of talent trained abroad with public funds and to put an end to unidirectional flows of scientific workforce in the periphery toward the
centres of scientific production. These mechanisms seek the reinforcement of the state, though they often fall short to assure that local scientific systems have the capacity to absorb this talent.

Recent political changes toward nationalism pose important challenges for future internationalisation policies. The paradigm of populist and nationalist movements in Latin American has changed significantly as shown by the case of Bolsonaro’s Brazil. These movements have now embraced far-right agendas and anti-systemic stances that call for depoliticising the state, and which stand in clear opposition to the ideas of the ‘movimiento desarrollista’ of the 1960s-70s and of the new regionalism of the first decade of the 21st century. I argue these new forms of nationalist agendas create new challenges in both the Global North and Global South in at least two fronts.

First, the rise of protectionist and populist movements could alter the balance between cooperation and competition in the definition of internationalisation. A frequently cited example of such balance is the concept of Europenisation, a restricted form of internationalisation conceived as a two-tier ‘system’ designed to balance cooperation and competition at the scale of Europe and the world simultaneously (ESF 2010; Van den Besselaar et al. 2012). The growth of Eurosceptic positions in Europe – and nationalist movements elsewhere – may not necessarily entail the end of internationalisation strategies, but could rather alter the cooperation-competition balance as policy initiatives favour notions of competition over cooperation in the promotion of internationalisation. In other words, the growth of nationalist positions in policy-making spheres could make future internationalisation policies less driven by goals of complementarity, collaboration and research excellence, but more so on enhancing competitive advantages that reinforce existing asymmetries and create new ones.

Second, the rise of nationalism could also bring new normative transformations. Thus far, internationalisation has been frequently placed in opposition to the notion of globalisation. In higher education, for instance, internationalisation policies are considered closer to the well-established tradition of international cooperation whereas globalisation strategies are commonly associated to the blurring of state borders and the promotion of market competition (van Vught, van der Wende, and Westerheijden 2002; Brandenburg and de Wit 2015). However, the new wave of nationalist and populist movements embraces a mix of anti-
globalisation, anti-integration and anti-cooperation attitudes that create a new type of normative tension in the definition of internationalisation. Nationalist policy agendas could force people to question the nature of internationalisation by denouncing that activities more related to the concept of globalisation (e.g. the commodification of higher education or science and the vanishing of state borders) are falsely executed under the flag of internationalisation (Teichler 2004; Brandenburg and de Wit 2015, 16–17). This is important because it implies deconstructing the notion of internationalisation, but in a different direction than this thesis has proposed. The emergence of nationalist perspective in science policy making could lead to depoliticise internationalisation policies and therefore reject internationalisation as an instrument to fight inequality and injustices in the international scientific system.

Overall, the main challenge posed by recent political changes toward nationalism lies in the struggle for the definition of internationalisation as a concept of change. To be successful future internationalisation policies should seek to establish a new balance between global integration and the promotion of internal capabilities. Supporting national scientific career paths with proper living wages or international partnerships that invest in local research infrastructures are examples of internationalisation policies that act as a motor for local and global change. Therefore, future internationalisation policies should continue to promote a fruitful engagement with the global scientific community while ensuring local talent has a future at home.


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7. PI-Argentina. 2018. Fieldwork interview 7; In person.
8. PI-Argentina. 2018. Fieldwork interview 8; In person.
17. PI-Argentina. 2018. Fieldwork interview 17; In person.
21. PI-Chile. 2018. Fieldwork interview 1; In person.
22. PI-Chile. 2018. Fieldwork interview 2; In person.
23. PI-Chile. 2018. Fieldwork interview 3; In person.
24. PI-Chile. 2018. Fieldwork interview 4; In person.
25. PI-Chile. 2018. Fieldwork interview 5; In person.
26. PI-Chile. 2018. Fieldwork interview 6; In person.
27. PI-Chile. 2018. Fieldwork interview 7; In person.
28. PI-Chile. 2018. Fieldwork interview 8; In person.
29. PI-Chile. 2018. Fieldwork interview 9; In person.
30. PI-Chile. 2018. Fieldwork interview 10; In person.
31. PI-Chile. 2018. Fieldwork interview 11; Skype.
32. PI-Argentina. 2018. Fieldwork interview 1; In person.
33. PI-Chile. 2018. Fieldwork interview 2; In person.
34. PI-Chile. 2018. Fieldwork interview 3; In person.
35. PI-Chile. 2018. Fieldwork interview 4; In person.
36. PI-Chile. 2018. Fieldwork interview 5; In person.
37. PI-Chile. 2018. Fieldwork interview 6; In person.
38. PI-Chile. 2018. Fieldwork interview 7; In person.
39. PI-Chile. 2018. Fieldwork interview 8; In person.
40. PI-Chile. 2018. Fieldwork interview 9; In person.
41. PI-Chile. 2018. Fieldwork interview 10; In person.
42. PI-Chile. 2018. Fieldwork interview 11; Skype.
43. PM-Argentina. 2018. Fieldwork interview 1; In person.
44. PM-Argentina. 2018. Fieldwork interview 2; In person.
45. PM-Argentina. 2018. Fieldwork interview 3; In person.
46. PM-Argentina. 2018. Fieldwork interview 4; In person.
47. PM-Argentina. 2018. Fieldwork interview 5; In person.
49. PM-Argentina. 2018. Fieldwork interview 7; In person.
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