



HAL
open science

Economic catching-up, Technological progress and Intellectual property rights

Anissa Saumtally

► **To cite this version:**

Anissa Saumtally. Economic catching-up, Technological progress and Intellectual property rights. Economics and Finance. Université de Bordeaux, 2017. English. NNT: 2017BORD0829 . tel-01701941

HAL Id: tel-01701941

<https://theses.hal.science/tel-01701941>

Submitted on 6 Feb 2018

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

THÈSE PRÉSENTÉE POUR OBTENIR LE GRADE DE

DOCTEUR DE L'UNIVERSITÉ DE BORDEAUX

ÉCOLE DOCTORALE ENTREPRISE, ECONOMIE ET SOCIÉTÉ N° 42

SPÉCIALITÉ : SCIENCES ÉCONOMIQUES

Par **Anissa SAUMTALLY**

**Economic catching-up, Technological progress and
Intellectual property rights**

Thèse dirigée par
Murat YILDIZOGLU
Professeur à l'Université de Bordeaux

Soutenue le 11 décembre 2017

Membres du jury :

M. DAWID, Herbert
Professeur à l'Université Bielefeld, **Rapporteur**

M. DOSI, Giovanni
Professeur à la Scuola Superiore Sant'Anna, **Président du jury**

M. VALLEE, Thomas
Professeur à l'Institut d'Économie et de Management de Nantes, **Rapporteur**

M. VERSPAGEN, Bart
Professeur à l'Université de Maastricht, **Examineur**

M. YILDIZOGLU, Murat
Professeur à l'Université de Bordeaux, **Directeur de thèse**

Rattrapage économique, Progrès technique et Droits de propriété intellectuelle

Résumé : L'objectif de cette thèse est de proposer une réponse à la question: Est-ce que les politiques de renforcement des DPI telles que les TRIPS peuvent être bénéfiques aux pays en développement et leurs perspectives de rattrapage économique.?

Le premier chapitre propose une revisite empirique et analytique du modèle de "catching-up and falling behind" de Verspagen (1991) qui se focalise sur l'étude du rôle des dynamiques d'innovation et d'imitation dans le processus de rattrapage économique. On trouve que même si la dynamique d'innovation est importante pour le rattrapage, la dynamique d'imitation se révèle nécessaire pour s'assurer que les pays en développement puissent développer leurs capacités qui leur permettront de prospérer. L'efficacité de la dynamique d'imitation est conditionnée par les caractéristiques du pays qui déterminent sa capacité d'apprentissage ("*Learning Capability*").

Le deuxième chapitre se concentre sur la compréhension du fonctionnement des transferts de technologie entre les pays développés et les pays en développement. On s'intéresse aux mécanismes derrière les deux canaux de transferts principaux, le commerce international et les IDE, qui sont les canaux les plus étudiés dans la littérature. On déduit de ce chapitre la richesse et la complexité de ces mécanismes.

Dans le troisième chapitre, on développe un modèle à base d'agents (ABM) pour représenter ces interactions Nord-Sud et leur complexité, avec une approche évolutionniste. Le modèle de base permet en particulier l'étude du mécanisme de transfert par la mobilité (locale) des travailleurs, un canal très peu étudié dans la littérature. Ceci nous permet d'étudier l'impact que les IDE peuvent avoir sur le développement et le rattrapage. On trouve que si les IDE des pays développés vers les pays en développement peuvent, sous certaines conditions, encourager les transferts de technologie et permettre ainsi le rattrapage, il y a tout de même des effets négatifs potentiels sur les industries locales, en particulier dans les pays les plus en retard. Le dernier chapitre propose une extension du modèle qui introduit les brevets. On observe que si les brevets permettent d'inciter les firmes du Nord à diffuser leur technologie et faciliter le rattrapage, ces firmes demanderaient une parfaite application des lois sur la propriété intellectuelle, ce qui serait trop sévère sur les firmes locales car cela bloquerait les imitations et surtout entraverait les efforts d'innovation de ces firmes, tout en procurant un bénéfice limité pour les firmes du Nord.

Mots-clés : Rattrapage économique – Propriété intellectuelle – Transfert de connaissances – ABM – Progrès technique – Marché du travail

Economic catching-up, Technological progress and Intellectual property rights

Abstract: The objective of this thesis is to propose an answer to the question: Can intellectual property rights policies such as TRIPS be beneficial for developing countries and their catching-up process?

We first look at the technological dynamics behind the catching-up process. The first chapter thus provides an empirical and analytical update on the catching-up and falling behind model by Verspagen (1991), which focuses on studying the role of the innovation and imitation dynamics in the catching up process. We find that while the innovation dynamics are important for the catching-up process, the imitation dynamics are necessary to ensure that countries build solid capabilities that will enable them to prosper. The efficiency of the imitation dynamics is dependent on policy factors that make up the learning capability of firms. The second chapter focuses on understanding the way those technological transfers from developed to developing countries can occur, we focus on studying the mechanisms behind two main channels, that is international trade and FDI, which represent the main form of North-South interactions studied in the literature.

In the third chapter, we thus build an agent-based model (ABM) to represent those North-South interactions and their complexities, with an evolutionary economics approach. The model allows us to study a particular mechanism: transfers through the local labour mobility. This allows us to study the impact FDI may have on development and catching-up outcomes. We find that while FDI from developed countries can, under the right conditions, encourage technological transfers and thus catching up, there are potential negative effects on local industries, in particular in countries largely behind. The final chapter proposes an extension of the model that introduces patents. We find that while patents help motivate northern firms to disclose their technology and thus facilitate development, those firms would require a perfect level of enforcement that will be too harsh on local firms, block imitations and also severely hinder the southern firms' innovative efforts, while generating limited gains for northern firms.

Keywords: Catching-up – Intellectual property rights – Technological transfers – ABM – Labour Market – Technological progress

L'université de Bordeaux n'entend ni approuver, ni désapprouver les opinions particulières émises dans cette thèse. Ces opinions sont considérées comme propres à leur auteur.

*"A learning experience is one of those things that says, "You know that thing you just did?
Don't do that." "*
– Douglas Adams, The Salmon of Doubt

Acknowledgements

I would first like to thank my thesis director, Prof. Murat Yildizoglu for allowing me to work on my topics of interest. This project turned out much more difficult than I had anticipated in many ways, and I am thankful that you helped me bring that work to a fine conclusion. Your persistence in always holding my work to the highest standards is greatly valued, and has helped me gain confidence in my work and abilities.

Pascale Roux, thank you for your kindness and your availability, especially in the last few days. I have come a long way since that first internship with you, and I am glad that you have been a part of the journey as a teacher and an advisor.

Emmanuelle Gabillon, I have thoroughly enjoyed working on your challenging classes and appreciate the exchanges we have had. Your trust and confidence in my abilities mean a lot.

Marc-Alexandre Sénégas, I appreciate the teaching responsibilities you have given me, and all the help and advice despite your busy schedule.

To the other members of the GREThA; professors, support staff and my fellow doctoral students thank you for creating a friendly atmosphere that made working here a pleasant experience.

Janpieter, (not) stupid genius, I am grateful for your friendship and ever beholden to you for all the help and support, be it technical, academic, or moral, that you have given me during those years. Sincerely, thank you.

Finally, I give my most loving appreciation to my mother and father for their endless support of my aspirations.

Bordeaux, December 11th 2017

Anissa Saumtally

Contents

Acknowledgements	5
Introduction	19
1 Catching-up dynamics: A first empirical approach based on Verspagen (1991)	27
1 Presentation of Verspagen's catching-up model	29
2 Applying the analysis to more recent data	37
2.1 The dependent variable: Time derivative of the technological gap	40
2.2 Explanatory variables	42
2.3 Observations on the data	46
3 Results	48
3.1 Estimation results	48
3.2 Analyzing the catching-up status of countries	53
3.3 Further analysis	57
4 Conclusion	69
2 Overview of the technological transfer channels to developing countries	73
1 Introduction	73
2 Transfers by trade	75
2.1 Imports of final goods	77
2.2 Imports of capital and intermediary goods	80
2.3 Exports	82
3 Technological transfers through FDI	83
3.1 Inter-sectoral transfers	86
3.2 Intra-sectoral transfers	89

4	Conclusion	94
3	North-South catching-up: an analytical approach using an Agent-Based Model	97
1	Introduction	97
2	The North-South Agent-Based Model	99
2.1	A general overview of the model	99
2.2	Sequence of operations	100
2.3	Agents and their basic interactions	102
2.4	Technology space	105
2.5	Skills, experience and training workers	109
2.6	The labour market	117
2.7	Production, demand and profits	124
2.8	Pricing Strategy	126
2.9	Sales and Profits	128
2.10	Tax Structure	129
2.11	Capital Investment	130
2.12	R&D: Imitation and Innovation	134
3	Running the model: Studying the general behaviour of the model	145
3.1	Variables of interest	145
3.2	Simulation Protocol	147
3.3	Results	149
4	Conclusion	190
4	The effects of Intellectual Property Rights on emerging economies: an application of the North-South Agent-Based Model	191
1	Introduction	191
2	The contentious aspects of TRIPS policy	192
2.1	A brief introduction on patents	193
2.2	The controversial aspects of TRIPS	195
2.3	The expected impacts of strengthening IPRs in developing countries	197
2.4	Positive evidence of the efficiency of stronger patent systems	198
2.5	A U-shaped relationship between IPR and development	199
3	The North-South ABM with Patents	201

3.1	Defining the different patent parameters	202
3.2	Enforceability	203
3.3	Decision to patent	204
3.4	The global knowledge stock	206
3.5	Effect on innovation	206
3.6	Effect on imitation	208
4	Are strong IPRs effective in helping the technological development of emerging economies?	210
4.1	Setting up the patents experiment	210
4.2	Results	211
5	Conclusion	223
Conclusion		225
Appendices		231
A Estimation of the model		233
1	Linear Specification	233
2	Non Linear regressions	235
B Analytical computations		237
1	Marginal effects on the speed of growth of the gap	237
2	Marginal effects on the learning capability	238
C Sample of countries		239
D Additional plots for the analysis on catching up		243
1	Policy efforts against the initial gap	243
2	Innovation against innovation effect on speed of growth of the gap	244
E The min function with decreasing returns		247
1	Planning desired capital and labour in the long term	248
2	The short term: adjusting labour to the current capital stock	250
3	Size of the firm and technology	253

F Simulations	255
1 Example of a run of the model in Netlogo	255
2 Initial Parameters	259
2.1 Parameters for both chapters 3 and 4	259
3 The case with no northern firms	261
4 Further plots and tables for the analysis	262
G Introduction - Version Française	275
Bibliography	279

List of Figures

1.1	Catching-up paths	35
1.2	Comparing datasets	39
1.3	World distribution of the trend in technological gap growth for the 1985-2010 period	42
1.4	Evolution of the trend within the period	47
1.5	Prediction quality of the retained model	51
1.6	Catching-up status analytically	54
1.7	Catching-up Status	55
1.8	Evolution from the 1965-1985 dataset	57
1.9	Countries stable points	59
1.10	Plotting stable points against level of research and initial gap	61
1.11	Imitation impact on the speed of growth of the gap against the initial gap	65
3.1	Technological space with two trajectories	107
3.2	Innovations on transitional trajectory: How the South catches up to the North	109
3.3	Box plots of the growth rate over time	150
3.4	Box plots showing the mean growth rates over 1000 periods according to the initial technological gap	151
3.5	Variation of the mean growth rate according to the number of northern firms	152
3.6	Mean effective productivity according to the initial technological gap: South vs North	157
3.7	Mean effective productivity in the industry according to the initial technological gap	158
3.8	South-North productivity differential according to the gap	159

3.9	Regression trees showing the variables and their value affecting the effective productivity of southern firms	160
3.10	Scatter plots showing the relationship between profits and capital at the 1000 period	162
3.11	Scatter plots showing the relationship between sales and capital at period 1000	163
3.12	Regression tree showing the impact of productivity on profits of the South	164
3.13	Southern Firms Survival Rate according to the Number of Northern Firms	166
3.14	Scatter plots showing the relationship between south firms concentration and the maximum profit reached by a Southern firm (at the 1000th period)	167
3.15	Concentration of labour in the industry and maximum level of profits reached	168
3.16	Regression tree for the average number of imitations per firm	169
3.17	Regression tree for the average number of innovations per firm	170
3.18	Determinants of knowledge stock for southern firms at the 1000th period	172
3.19	Number of imitations by the South necessary to catch up, by technological gap	173
3.20	Proportion of northern workers in southern firms and mean number of imitations (1000th period)	174
3.21	Mean proportion of northern workers in southern firms	175
3.22	Regression tree: proportion of northern workers in southern firms	175
3.23	Mean proportion of northern workers in southern firms according to contract length (at the 1000th period)	176
3.24	Regression tree: proportion of cases where the whole southern industry on average has technologically outperformed the northern firms	178
3.25	Boxplots of unemployment rates observed according to the contract length (at the 100th period)	179
3.26	Unemployment rates over time	180
3.27	Employed population over time	181
3.28	Scatter plots showing the relationship between wages and skill level attained at the 1000th period	182

3.29	Factors affecting the wage discrepancy between northern and southern firms (1000th period)	184
3.30	Wage inequality and South (red dots) and North (blue dots) wage level .	185
3.31	Wage inequality and technological gap	186
3.32	Wage inequality and technological gap in caught up southern industries .	186
3.33	Productivity loss over time	188
3.34	Total productivity gained by workers through training (at the 1000th period) per gap	188
4.1	Southern productivity according to gap, $t = 1000$	214
4.2	Southern average profits according to gap, $t = 1000$	214
4.3	Regression Tree showing the effect of different variables on the number of northern patents per northern firm	215
4.4	Regression Tree showing the effect of different variables on the number of southern patents per southern firm	216
4.5	Mean number of patents per firm, per level of patent breadth $t = 1000$. .	217
4.6	Number of northern patents at $t = 1000$, by level of enforcement	217
4.7	Ratio of innovations kept secret to innovations patented by the North, at $t = 1000$	217
4.8	Regression Tree showing the effect of different variables on the total number of innovations kept secret at $t = 1000$	218
4.9	Number of imitations per southern firm, by enforcement levels	218
4.10	Number of periods necessary to catch up, by enforcement levels	219
4.11	Southern firms' mean knowledge stock at $t = 1000$, by enforcement level	220
4.12	Innovations by southern firms at $t = 1000$, by enforcement level	220
4.13	Mean Profits of southern firms $t = 1000$, by enforcement level	221
4.14	number of north patents, per firm $t = 1000$, by enforcement level	222
4.15	Profits of northern firms at $t = 1000$, by enforcement level	222
4.16	Mean Profits of northern firms $t = 1000$, by enforcement level	223
E.1	Profit functions for different levels of fixed capital	252
F.1	Example of an initial point of the interface	256
F.2	Technological space after 1000 periods	257

F.3	Example of plots produced after 1000 period run of the model	259
F.4	Mean profits of southern firms when there are no northern firms, per contract length, at the end of the 1000 runs	262
F.5	South mean effective productivity according to the number of northern firms	262
F.6	North mean effective productivity according to the number of northern firms	264
F.7	Mean effective productivity in the industry according to the number of northern firms	264
F.8	South-North productivity differential according to the number of northern firms	265
F.9	Scatter plots showing the relationship between profits and effective productivity at the 1000 period	265
F.10	Scatter plots showing the relationship between profits and capital for all periods	266
F.11	Scatter plots showing the relationship between sales and productivity (at period 1000)	266
F.12	Scatter plots showing the relationship between total mean capital investment and productivity (Southern firms, all periods)	267
F.13	Violin plots showing the distribution of profits in the South according to the number of northern firms (at the 1000th period)	267
F.14	Violin plots showing the distribution of profits in the South according to the technological gap (at the 1000th period)	268
F.15	Regression tree showing the factors that influence the survival of southern firms (at the 1000th period)	268
F.16	Survival rate of southern firms and mean profits reached by northern firms	269
F.17	Regression tree for the average level of knowledge per southern firm at the 1000th period	269
F.18	Regression tree for the average level of max productivity reached by southern firms at the 1000th period	270
F.19	Regression trees for South wage levels (at the 1000th period)	271
F.20	Regression trees for North wage levels (at the 1000th period)	272
F.21	Violin plots of the wage differential according to the number of northern firms)	273

F.22	Scatter plots showing the relationship between productivity and skill level attained at the 1000th period	273
F.23	Violin Plots : Productivity loss by gap at the 1000th period	274
F.24	Violin Plots : Productivity loss over time at the 1000th period	274

List of Tables

1.1	Descriptive data	46
1.2	Correlation table	47
1.3	Estimations for non-linear model	49
1.4	Evolution of the gap: Predictions vs. Empirical observations between 1985 and 2010	53
3.1	Determining job vacancies under different configurations	120
3.2	Treatment variables	148
3.3	correlation coefficient table of the explanatory variables	153
3.4	Probability of catching up: Logit regression output	153
4.1	When can an innovation be patented and/or used ?	208
4.2	Treatment variables	211
4.3	correlation coefficients of the regression variables	212
4.4	Probability of catching up: Logit regression output	213
A.1	Estimations for linear model	233
F.1	Initial Parameters for simulations	260
F.2	Explaining the speed of catching-up	263

Introduction

Introduction

Today's developing world faces a technological environment that is ever increasing in complexity as advanced economies continue to push the technological frontier. Their development challenges far differ from the context that saw the rise of Asian tigers in the post-World War II era, decades ago. As they move on to a knowledge-based economy, advanced countries are now heavily dependent on knowledge creation to the point that technology policy has become paramount at the national and the international level. Thus while advanced countries look to influence international policy, one has to consider the repercussions on developing countries.

The reliance on technological advancement and the fact that technology becomes increasingly expensive to produce create a context where the importance of intellectual property rights has been amplified. As globalisation has increased the economic interactions between countries, the need to protect technologies beyond countries' own borders lead to the enactment in 1994 of the trade related agreements on intellectual property, known as TRIPS, which set intellectual property standards for all member states of the WTO, which totals today 164 countries, implying that nearly all countries have agreed to align their intellectual property (IP) policy with the WTO recommendations. While for developed countries this alignment required almost no change, since TRIPS followed their national policy trend of reinforcing patents, developing countries had to set "stronger" IP laws to comply (Cimoli et al. (2011)). This is likely an unwanted move by developing countries otherwise their policies would have been already compliant with TRIPS. This implies a significant change in policy for developing countries, and as Wade (2003) calls it a reduction in their "self-determination" ability. The main question that thus guides this thesis is: Is TRIPS compliance a beneficial move for the economic advancement of developing countries?

I should point out that this is not a new question (for example Drahos (2002)). The

debate surrounding TRIPS and its effects on developing countries has attracted theoretical and empirical studies, both resulting in contrasting conclusions. The discussion is thus still on going (see Lall (2003)). In addition emerging countries such as India and China are also starting to become important actors of international technological advancement as evidenced by the fact that their patents filings are increasing (Godinho and Ferreira (2012), which also shows that they are increasingly using the IPR system). The challenges for developing economies are thus not necessarily the same as when TRIPS were first signed.

Throughout history, IPR policy's aims have ranged from incentivising research and rewarding innovation, motivating technological disclosures, and preventing imitation. And today, firms use it as a strategic tool by building patent fences to ward off competition (Cohen et al. (2000)). IPRs can thus affect technological and economic development in diverse directions. It pushes for innovation while restricting innovation and at the same time allows for sharing of knowledge. And in parallel, the market effects of creating monopolies and blocking potential competitors can affect the performance of firms and industries, which can be even more problematic for developing countries with technology-intensive sectors still in their infancy, thus affecting their growth. Through TRIPS, IPR are taking an international turn.

In order to bring a contribution to this discussion, this thesis proposes to trace back to the main stakes for developing countries, that is their prospective catching up. The thesis is thus organised in a manner that is reminiscent of its title "Economic catching up, technological progress and IPR" and follows the logic of the investigation process of the main question. Therefore regarding the question why IPR (and thus TRIPS) matter, we would have to look at how they affect the technological development. And at this point we would need to consider why technological development is important for developing countries. This has been answered very early on, one needs to look no further than the Solow model of growth (Solow (1956)) where (exogenous) technological progress was essential to foster continual growth. Or beyond this, the endogenous growth theories (Romer (1990), Aghion and Howitt (1990)) that considered technological progress to be fostered by growth itself. Thus while it needs no reminder that technological development is necessary for catching-up, a question we will be looking to answer in relation to this is what form should that technological development take for developing countries, that is should countries rely on existing technologies (imitation) or look to develop their own

(innovation). The duality in the role of either imitation or innovation for development is particularly relevant as we consider the potential effects of IPR.

The first chapter of this thesis proposes an analysis of developing countries and their catching-up successes (or failures) by providing an update to Verspagen's "catching up and falling behind" model from 1991. This model looks into precisely the role played by imitation and innovation for developing countries, and our conclusions, drawn from an empirical analysis that updates the results of the original study, help us explain that while innovation can be a driver of growth to some extent, developing countries, due to their limited capabilities, benefit more from imitation, at least in the early stages of development. The term "imitation" here refers to the use of technologies already developed by more advanced countries.

The fact that developing countries are reliant on technologies developed by advanced economies means that their interactions with those countries are important to consider as they should facilitate developing countries' access to these technologies and thus enabling technological transfers. Countries' technological development is contingent upon the technological advancement made by their firms. Therefore we have to look at how technology is transferred between firms. The channels and the mechanisms behind those transfers are studied in the second chapter. I discuss North-South interactions such as FDI and Trade and how they can facilitate or hinder technological transfers. Studying the mechanisms behind those channels of transfers allows us to understand better how technology is transferred and thus how can IPR policy impact transfers.

The novelty of this thesis resides in how I chose to answer the question. I develop in the third chapter the North-South ABM, an agent based model to study North-South interactions. If the term sounds familiar, it is because many, if not all, of the theoretical approaches aimed at studying the interactions between developed and developing countries have been based on the North-South general equilibrium model by Grossman and Helpman (1991). The ABM borrows that name because it is essentially modelling a similar setting, though in a completely different theoretical approach. What I learned from the mechanisms behind the channels of transfers, and the complex role of innovation and imitation in the development process, is that the catching up process is made up of sophisticated interactions between countries and their actors (firms and workers). Furthermore I find that there is an ever-changing technological environment and the evolution of firms throughout their

interactions with other firms echoes those changes.

The evolutionary approach is perhaps best suited to represent this ever changing environment. Though the term was first used by Veblen (1898), the actual foundations of this approach were mostly laid down by Nelson Richard and Winter Sidney (1982) who developed the theory. A key concept underlying the theory is the idea that agents make decisions under the assumption of *Bounded Rationality*. This assumption resides in the fact that agents face limitations that restricts their perception and understanding of the problems and situations they face. The principle is particularly relevant for development economics, as governments face challenges that are new and complex. Furthermore, countries' own characteristics, be it cultural, social, economic or technological, are so diverse across the globe that it becomes difficult for policy makers to make the best possible decision. Under bounded rationality, the decision making process is best described by Nelson and Winter's (1982) "routines". They consist in a set of rules that guides agents in their decision making process according to what they observe and what they know from experience. As such the theory is deeply rooted with the concepts of learning and adaptation.

As Lall (2000) argued, development economics may be best perceived through that evolutionary lens given the importance of the technological process for development. Technological development is one of the prime examples for how economies are dependent upon these adaptive and learning mechanisms (Dosi and Nelson (1994)). The entire process of acquiring, assimilating, using and improving the technology is based on selection, learning and adaptation.

With regards to development Lall explains how capabilities affect development. The idea behind this is reminiscent of how Abramovitz (1986) viewed the catching up process, as conditional upon policy making through social capabilities, but the role here is beyond just a set of characteristics, it stresses out the role of "complex skill, experience and effort that enables a country's enterprises to efficiently buy use, adapt, improve and create technologies". That is the technological advancement of countries is not just the result of policy making but the interactions of those characteristics that define a learning and adaptive processes. Following Lall's argument, Nelson (2008) thus makes the case for the use of evolutionary lens to study development and catching-up and writes that "*the key driving force of catch-up is assimilation, learning to do effectively what countries at the frontier have been doing, often for some time.*". The processes of assimilation and learning

are dependent upon the complex economic, political and technological interactions. It is in light of the complexities involved in the catching-up process, and to better capture the effect of systemic interactions that we cannot be satisfied with general equilibrium models.

Agent-Based Models are the perfect tool to engage in an evolutionary thinking of the interactions of agents and model complex systems. ABMs are particularly interesting because they provide an economist with a laboratory for policy testing. Through computational economics, ABMs can represent the complex systems that are inherent to macroeconomics, as well as simulating adaptive process specific to technological learning. There have been example of ABMs used as a macro-policy analysis tool. Bergmann (1974) designed the US money flow model between households firms and banks, Eliasson (1977) used the MOSES agent based model representing the Swedish economy and Dosi et al. (2010) built the keynesian model with technological learning. Perhaps one of the largest projects is the EURACE model Dawid et al. (2014) representing the european economy and its interactions with regions, that aims to be used as a policy making aiding tool. More related to our question, Silverberg and Verspagen (1994)'s model focus on innovation and growth.

The North-South ABM model proposes to represent many facets of the economy, a local labour market, a skill learning and transferring system through the workers, as well as an R&D process and adaptive production system.

In the spirit of the macro-models cited above I attempt to use the North-South ABM as a base to study policy effects on catching up, with the addition of the "patents" extension in chapter 4, thus bringing an answer to the original question. This last chapter also serves as an example of how the North-South ABM may be used to examine other policies that affect developing countries and their interactions with advanced countries.

Therefore, while this thesis has been guided by a simple question, it is much more a work of exploration and experimentation of domains (catching up, technological development IPR policy) that have been studied substantially, yet call for a new approach.

Chapter 1

Catching-up dynamics: A first empirical approach based on Verspagen (1991)

Why do some countries flourish while other struggle to offer its population prosperous outlooks? This is the question that is at heart of studies of catching-up. Understanding what fosters economic growth and development would allow for developing countries to have recommendations that will guide them in ensuring a successful development path. Growth theories have early on identified the role of technological progress in for economic growth (see Solow (1956), Aghion and Howitt (1990)).

Beta-convergence advocates have argued that catching-up happens automatically (see Barro et al. (1991) for the US). The reasoning was that countries that were particularly behind should observe a high growth rate at first because of all the opportunities for technological learning that exist due to their distance with the technological frontier. This did not happen as we continue to observe disparities that are even sometimes increasing. The other strand of the literature, the conditional convergence, explains that convergence will happen provided countries have sufficient capabilities to do so. An example would Abramovitz (1986), who develops the concept of "social capabilities", a set of necessary characteristics such as education, politics, or infrastructures that can define the abilities countries will have to catch up. Conditional convergence is also observed in groups, where similar countries (in terms of capabilities) tend to observe a similar development and converge towards one another (Quah (1997)).

Through those two strands of the literature, we can identify two dynamics. First the more behind a country is, the more opportunities to grow it would have. Second, only

countries sufficiently developed will succeed in progressing in technology and thus grow to catch up.

The framework devised by Verspagen (1991) links technological development dynamics and those two effects. Specifically, he considers that countries that do not have sufficient abilities will see their economic gap (as measured by the GDP/capita ratio between the developing country and the technological leader) grow, because they fail to sufficiently gain from the technological opportunities. The gap grows not because the economy of the developing country is receding, but rather because the technological leader keeps pushing the technological frontier. Two mechanisms are identified: the role of imitation in stopping the growth of the gap, that is countries must be able to sufficiently absorb technologies, and the role of innovation of the developing country in closing in on the gap. As such, through this model we are able to see the different roles played by innovation and imitation at different development phases. It is in this regard that this model is particularly interesting for us as we try to understand the role technological transfers may play in the development process.

The theoretical model is estimated and tested empirically and allows to classify countries according to their catching-up status, mainly he identifies countries that are falling behind but could be catching up, those that because of their characteristics have no chance of catching up without making significant policy changes, and those that are catching up.

The empirical study was based on data from 1965 to 1985. In this chapter I propose to update the study by estimating the model over a more recent time frame, from 1985 to 2010. This will allow us to test if the model is significant today. We will also try to draw comparison between the two results, and see whether predictions from the model are still true today, if countries have managed to improve or if their economic situation have worsen.

Our second purpose is to look closer at the those imitation vs innovation dynamics as modelled by Verspagen and how they affect development outcome. In order to make our estimation for the 1985-2010 period, we choose to follow a similar procedure (or as close to it as possible) as the original version. Therefore, the aim of this chapter is not to improve on the original model, but rather to explore what this model can offer in terms of analysis of technological development dynamics.

The chapter is thus organised as follows: we will first present the theoretical model.

Section 3 looks at the dataset used for the empirical analysis. Section 4 presents the results of the estimation and the analysis in two part, one comparative study and a proposition to extend the scope of analysis of this model. The final section concludes and gives perspectives on the benefits of this analysis for the work ahead.

1 Presentation of Verspagen's catching-up model

We here give a simplified account of the model devised by Verspagen in order to use it as our framework for our analysis.

Let us first present the dependent variable as defined by Verspagen. The model aims at explaining the dynamic of the technological gap. The approach taken looks at the speed of growth of this gap. The analysis is centered around its value. The gap G will take a positive value when country is behind the leader, and a negative one if it happens to be ahead, or more logically, if two countries have the same level of technology, then the gap will be 0. If a country is catching up, then the growth rate of the gap should be negative (i.e. the gap closes). If a country is falling behind then the gap should be widening, its growth rate is positive. This gives the general guideline regarding the dependent variable.

The model in the original paper spans the years 1965 to 1985, instead of using the growth rate of the technological gap for the whole period, a new variable relating the average annual trend of the evolution of the technological gap is generated by the author. This trend is evaluated through a simple OLS estimation to draw trends for each individual country regarding their gap progression. If the gap at year t and for country i is represented by the variable G_{it} (see next section for modelling the variable), then we estimate the trend through the following equation:

$$G_{it} = a_i Year_t + b_i + \varepsilon_{it} \quad \text{for every country } i, \text{ at year } t. \quad (1.1)$$

The a_i will be a country characteristic, later denoted *timeG* and will be a country specific variable for the whole period. b_i is a country specific constant. The dependent variable of the full model is thus this a_i . The “time derivative” (a_i) of the preceding equation may be interpreted as such: all else equals, the gap measure chosen G_{it} grows by

a_i each year. It is therefore a variable relating to the average annual growth rate over the period.

While tracing the evolution of the technological gap, the model represents two dynamics in play. As the framework is that of one leading country and multiple followers, the growth of the technological gap is subject to two effects to be taken into account:

- The technological gap widens systematically. This is due to the assumption that the most advanced country has higher R&D capabilities than the follower, because it has at its disposal a greater stock of knowledge. As those capabilities are considered fixed over the period chosen, the leader will be in a position to increase the gap during the whole period due to the theoretical superiority of its innovative capabilities¹.
- There are however potential counteractive effects. A follower is able to imitate the leader, thereby reducing the gap. The imitation capability is dependent upon the learning capability of the country, and allows a follower country to gain more advanced technologies from the leaders.

The first effect is considered exogenous. Each country's research level over the period is evaluated, and if one country is more performant than the other in terms of innovation, this will reduce the gap between this well performing country and the leader, or if the country was a leader, it would widen it in its favour. It is referred to as the exogenous rate of growth of the technological gap because it is assumed that the leader has a greater technological stock which increases with its high R&D capabilities. Thus, this effect captures a phenomenon where the technological gap between two countries increases just because of the advantages the leader has. It is exogenous because if all else is equal over time, this dynamic will persist and remain constant. This is in opposition with the second effect mentioned, where the dynamic is guided by spillovers and as such the effect is meant to change over time.

The level of innovation in a country is measured in the original paper by the per capita number of patents held by residents of country i at the USPTO variable (we denote it PAT_i). The first effect on the rate of growth of the gap is thus captured by $\beta_0 + \beta_1 PAT_i$, the higher

¹While this holds true in the original paper, we will find in our dataset that certain countries have higher R&D capabilities than the chosen leader (the US), which will lead to a different commentary regarding the development dynamics between those countries and the leader.

the innovative capacity of the country i , the less the gap will grow due to innovation (we expect $\beta_1 < 0$, β_0 is a constant).

The second effect is more complex. Referring to simpler models, there is the assumption that if the gap is larger, then the follower country has much more technology to imitate, and therefore will catch up at a higher speed at first. As more and more technology is being imitated, the pool of available yet unknown technologies gets smaller, and the more difficult successful imitation becomes. There are diminishing returns, the closer to the technological frontier one country is, the lower the speed of catching up. Therefore, there should be a negative relationship between the initial gap and the gap growth rate: that is the larger the gap, the lower the gap growth rate² (i.e. the country is catching up faster). This is true under the assumption of diminishing returns of technology. However, Verspagen presents the idea that this technological gap only represents the potential of technological spillovers from leader to follower. The actual spillovers will also depend on the ability of the country to assimilate such available knowledge, this is dictated by the learning capability. The latter will depend upon different policy elements. Those policy elements highlight the public investment to increase the technological level of the country. They represent the instruments a country may use to improve the technological conditions of the country. The variables retained in the model to represent this policy space are education and infrastructure. This is because education represents the development of human capital, which, if properly trained, would be more able to assimilate new technologies. The infrastructure available in a country makes it more or less possible to assimilate new technologies; for example, if a sector grows through the development of the internet, poor telecommunications networks would make it impossible for this country to assimilate new technologies in that sector. We note that a country with a high technological gap will tend to have low learning capabilities (see for example the negative correlation between education and initial gap in the appendix). Other elements could be included (i.e. political climate), though given that we are working with developing countries with limited data availability, a more complex model would be difficult to put into application.

This highlights a paradox for the effect of the initial gap on catching up: with a high initial gap, a country has a high chance of potential imitation, however, its ability to do so is limited. These countering forces are what makes the technological catching-up not so

²The literature on Beta-convergence highlights a similar dynamic.

automatic.

In Verspagen's model, the effects from imitation on the growth of the gap are modeled as such³:

- We have the first theoretical effect which assumes that the larger the technological gap, the more there is to learn, and thus imitation should be more important: we denote this direct effect $\beta_2 * G_0$, with $\beta_2 < 0$ and G_0 is the initial gap. The larger the gap, the more imitation is possible, thus in theory the speed of growth of the gap should decrease (see also Barro et al. (1991)). Because the model is estimated for the overall period, and not year by year, the analysis is based around the initial gap. The variables used in the model are for the whole period, and therefore they capture the realised potential during the period and their eventual evolutions. The use of the initial gap is thus justified by the fact that it represents the potential of the country for the period.
- However, the effect of β_2 does not affect the whole gap in technology. Rather, only a fraction of this missing technology maybe learned by the country and this is dictated by the learning capability. The learning capability is expressed as such: $e^{\frac{G_0}{\delta * policy}}$, where G_0 is the initial gap, *policy* is a vector of policy variables and δ the vector of coefficients associated with such policy variables (δ expected to be negative). Those variables may include any policy elements which facilitates imitation such as education, infrastructure, political environment etc. The policy coefficients must be negative so that as its respective policy variable increases, the learning capacity increases (all else equal), and thus there is more imitation which slows the speed of the gap increase. We also notice that the learning capability depends in the technological gap. This is to say that for a similar gap, the country with the higher policy characteristic (such as education) will be more successful at imitation. This rests on the assumption that $\delta < 0$, in which case $\frac{de^{\frac{G_0}{\delta * policy}}}{dG_0} < 0$, so as the gap increases, the learning capability decreases.

The variables for policy retained in Verspagen's model are education and infrastructure.

Education is given by two variables: EDU_1 and EDU_2 , representing respectively the levels

³Those comments regarding the basic working of the model hold true for countries with a positive initial gap, that is countries behind the leader. The interpretation changes slightly in the case of a negative initial gap. These special cases are discussed in the appendix.

of primary and secondary education. The idea behind the use of those two variables is that they do not translate the same level of skills of the population. Primary education corresponds to basic skills, whereas secondary educations communicates a more advanced skill level. The infrastructure (*INFRA*) is proxied by the electricity capacity in the country, mainly because it represents the level of basic infrastructure, and thus the environment for economic development. Similarly, if two countries have the exact same characteristics, except one has a larger technological gap, its policy variables will not be as successful as the country with a smaller gap, and further efforts will be required.

A nonlinear model is thus best suited to represent those contradicting effects of the initial gap. The model specification is as follows:

$$timeG = \beta_0 + \beta_1 PAT + \beta_2 G_0 e^{\frac{G_0}{d_1 EDU_1 + d_2 EDU_2 + d_3 INFRA}} + \varepsilon \quad (1.2)$$

with *timeG* the speed of growth of the technological gap, *PAT* the variable expressing the exogenous research output produced by a country relative to that of the leader (so that we expect $\beta_1 < 0$). *timeG* is the dependent variable. It represents the overall speed of growth of the technological gap. It is assumed that the gap grows because of the relatively high research level supposedly maintained by the leader. For $timeG > 0$, a higher *timeG* will lead to an increase of the gap at a faster pace than with a lower (yet positive) *timeG*; whereas a negative value represents a gap which is closing. G_0 is the initial technological gap at the beginning of the period studied. EDU_1 and EDU_2 are variables which measure education levels, and *INFRA* measures infrastructure level. These variables, along with *PAT* are taken for the whole period, meaning there is one value for each of those variables representing their respective level for the 1965-1985 period. $\beta_0, \beta_1, \beta_2, d_1, d_2$ and d_3 are the coefficients which measure the effect of each variable to be estimated. ε is the error term.

The analysis by Verspagen is based on that equation which is a simplified version of his theoretical model⁴. Going back to the two effects, we can decompose the righthand side of this equation into two parts: the first part represents the exogenous growth of the technological gap captured by $\beta_0 + \beta_1 PAT$ and the second part is the endogenous growth (or reduction) of the gap; the endogeneity comes from the dependence on the initial gap G_0 .

⁴In the original paper, the theoretical model is represented under a different form. The formulation presented here and on which we base the subsequent analysis corresponds to the retained empirical specification in Verspagen's thesis.

In this paper, the point of interest is the point where the gap stops growing, that is when the effects from imitation equal the effects of the natural gap growth. We thus solve the equation $\beta_0 + \beta_1 PAT = -\beta_2 G_0 e^{\frac{G_0}{d_1 EDU_1 + d_2 EDU_2 + d_3 INFRA}}$ for G_0 . The value obtained if it exists is the root1 point (figure 1), in which case $timeG = 0$. The root1 point is a theoretical gap specific to each country given their characteristics and parameters. If the country manages to converge towards this point, the gap will stop growing.

It is not convergence, not full catching up as there is still a gap persisting and progress to be made. We can consider if a country has reached this point where the gap cannot worsen anymore, then it has been on the catching up path.

If we plot each part of this equation, as presented in Chapter 5 of Verspagen's thesis, we can obtain figure 1.1 which compares the two effects. The blue (here flat) line represent the exogenous technological gap growth, whereas the green curve represent the actual spillovers received by countries conditional upon their learning capability made up by policy characteristics in this model. Verspagen shows that the red dot, which will refer to as root 1, represents a stable point towards which the technological gap may converge. The other intersection, if there is one, is a point of divergence, that is if countries have an initial gap situated to the right of this point, then they are falling behind. The exogenous rate of growth will, barring any policy effort, forever outweigh the spillover effects, thus furthering the technological gap. It can happen that countries do not have any root point. In that case it means that their characteristics do not permit them to stop the technological gap from growing, and they are drifting further away from the technological frontier. If they find their initial gap to be in the zone where the curve is above the line, then these countries are gaining enough from technological spillovers to outweigh the effects of the natural growth of the technological gap. They will thus catch up up to a point where the gap no longer grows. It is important to stress that even though the gap stops growing, it still persists, and in order to really close it, a modification of the characteristics will be required to move the root to point where there is in fact convergence in the traditional sense, that is the gap has reduced to 0 (see section 3). Finally, if the country has its initial gap smaller than its root, then all else equal, it is expected that they will increase their gap to the root point where the gap will stop evolving. When the stable point is reached, the gap will have increased from its initial value.

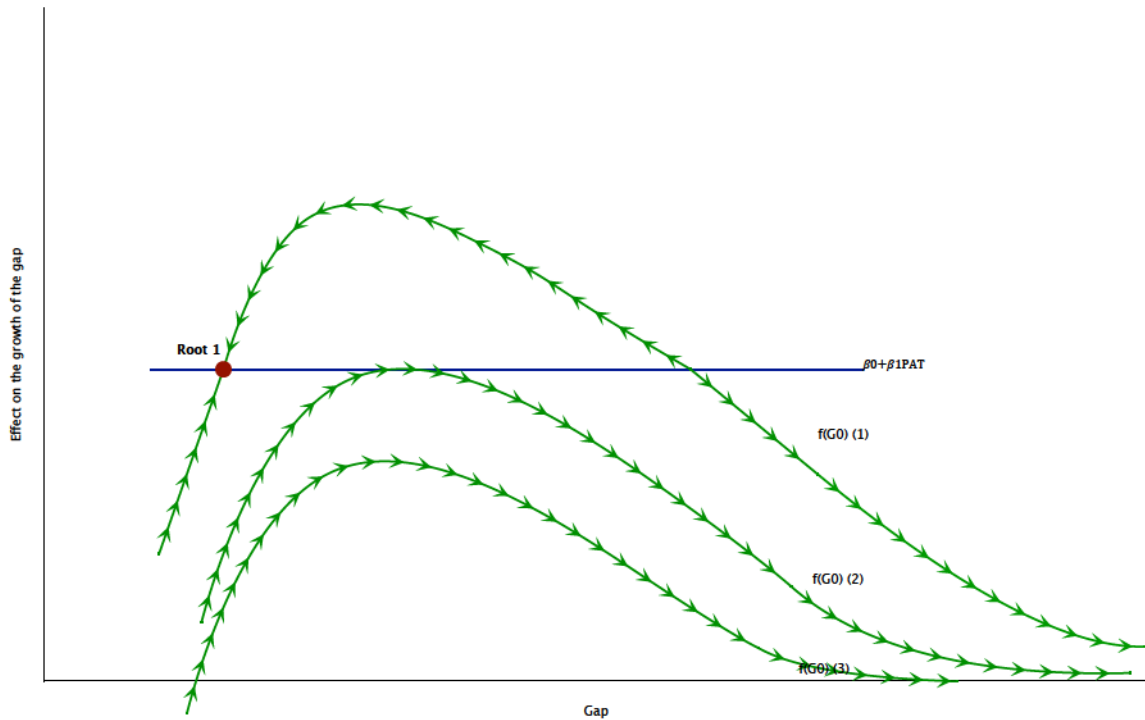


Figure 1.1: *Catching-up paths*

It should be mentioned that once the point we call root1 is attained, in theory, the gap stops growing. It is not convergence per se, however, it suggests that countries have reached a point where, all else equal, they cannot fall behind anymore. They remain at a point where their relative gap with the leader is potentially stable. True catching up is obtained by modifying countries characteristics, akin to policy efforts. In this model, an exogenous (positive) change in those elements can lead to two situations: Either the learning capability increases and this increases the quality of imitation (i.e. the amount that can be absorbed), or the innovative capacity increases. If only imitation capabilities are improved, then the country is stuck as a follower with always a lag behind the leader (that is if imitation capabilities are maxed out, then the follower has to wait for the leader to develop something new to be able to copy it later.). The only “true” catching up is achieved if innovation capabilities are improved, and thus generates the possibility that the follower country can rival the leader and present itself as a competitor rather than a follower.

When it comes to the real world, there is hardly one leader, despite what statistics say. Whether technological level is measured through patenting, publications, productivity or else, the most advanced economies do rival each other; i.e. it is difficult to suggest that the USA and Japan are in a leader-follower dynamic when it comes to technology. It is

in that sense that seeing the technological gap reaching a stable value can be considered as catching up: the gap does not increase, it persists, and offers the follower country the opportunity to enter a new “phase” through national efforts. It is also because the model is static (i.e. one variable for learning capability or innovation for the whole 20 year period) that we can reach this conclusion. As the variables do not vary within the model (no endogeneity), the duality of the two forces at hand (innovation lead of the leader vs imitation of the technologies yet to learn) will lead at best to a point where they compensate each other. To move past this point would require moving the root itself towards zero (i.e. where the stable gap is closer to 0), which implies by construction a change in the core characteristics of countries.

The main dynamics which is captured by this analysis may be summed up as imitation vs. innovation. What drives the leader to increase the gap is its ability to innovate, and what allows countries to close in on this gap is their ability to imitate the leader. When the stable point is reached, it should be interpreted as if countries have exhausted their imitation potential, and thus two possibilities open up: either they develop their learning capabilities to imitate some more, in which case they remain in a leader-follower dynamic, or they increase their innovativeness, allowing them to actually surpass the leader. If they maintain a status quo, nothing stops the leader from innovating further (exogenously), thus causing a shift of the stable point for those countries which might increase the distance to the technological frontier.

The analysis thus conducted by Verspagen and here replicated with more recent data consists in estimating the coefficients, and then for each country find out whether they are catching up or falling behind using their specific attributes.

We note that Verspagen conducted linear and non-linear estimations of the model and concluded that the non-linear model held a higher explanatory power. We are taking this as granted as the non-linear model features some interesting aspects (such as the existence of stable points), which cannot be modeled with a linear specification. More importantly, the non-linear model is more apt to represent the effects of the learning capability of countries. The linear version (with its variations) is given by equation (2), with the corresponding variables as the retained nonlinear specification, although it does not permit

us to conduct the analysis described above through equation (1).

$$timeG = \beta_0 + \beta_1 PAT + \beta_2 G_0 + d_1 EDU_1 + d_2 EDU_2 + d_3 INFRA + \varepsilon \quad (1.3)$$

In terms of our expectations of coefficients, we expect all of them to be negative, as each variable is expected to help closing the gap, therefore reduce the speed of the growth (if not invert it completely). This is also true for β_2 , as consistent with the idea that the more important the initial gap, the higher the potential for spillovers, although this could be disputed. Furthermore, because we expect $\beta_1 < 0$, we should expect in most cases $\beta_0 > -\beta_1 PAT$. If that is not the case, then the blue line will be under 0. The implication of this is that the country in question is a potential leader, and is probably outperforming our leader (here chosen as the US).

The result of these estimations, as well as some comments are presented in section 3. The next section first discusses data used.

2 Applying the analysis to more recent data

The aim of this part is to see if there are evolutions of results regarding countries and their catching up situation from the findings in Verspagen (1992).

The data used here is from 1985 to 2010; the original work had data spanning from 1965 to 1985. Obviously, certain countries did not exist in 1985, yet we still include them. The sample is presented in appendix C, where the start date for each country is also given.

We used 111 countries, noting that there are some missing data. The use of cross sectional estimation allows for dealing with some missing information. The rationale behind it is that because we are using most indicators as country characteristics only (i.e. not for each year specifically, so we only need one global observation per country), we can use averages over the chosen period to represent that country. Nevertheless, a disclaimer should still be mentioned as the data might be subject to bias from the generation of aggregates to compensate for missing data. The fact that there is missing data creates a loss of information and as such affects the accuracy of the data. The missing years could be due to historical reasons, for example, all former USSR countries do not have observations at the beginning of the period; or some developing countries have only recently started to report accurate statistics systematically. This would imply a potential positive bias in

terms of value reported, as it is likely that development indicators (education, GDP per capita) were lower in the early years. Or it could very well go the other way, by seeing that the former USSR countries were going through a transition period. However, being more lenient with the data allows for having a more balanced and larger sample of countries.

This version contains a few more countries than the original work. We chose in general to omit the smallest countries used by Verspagen (i.e. Trinidad and Tobago) in order to avoid scale issues, biases and significant missing information problems, which is also the case for many sub-Saharan countries. Furthermore, given the choice of the dependent variable, not all oil countries are present in the sample because of the bias they would experience. Since the dependent variable is constructed through the GDP per capita, those countries tend to experience high level of GDP per capita due to the income generated by the petroleum industry. For those instances, the GDP per capita hardly captures the technological level (as it was intended by the choice of the proxy), thus the presence of those observations would cause a bias, as their actual technological performance is not comparable to developed nations experiencing comparable GDP per capita. Additionally our analysis features some of today's key players (China, Russia). Countries which did not exist at the time also contribute to increase our sample size (ex-USSR, ex-Yugoslavia).

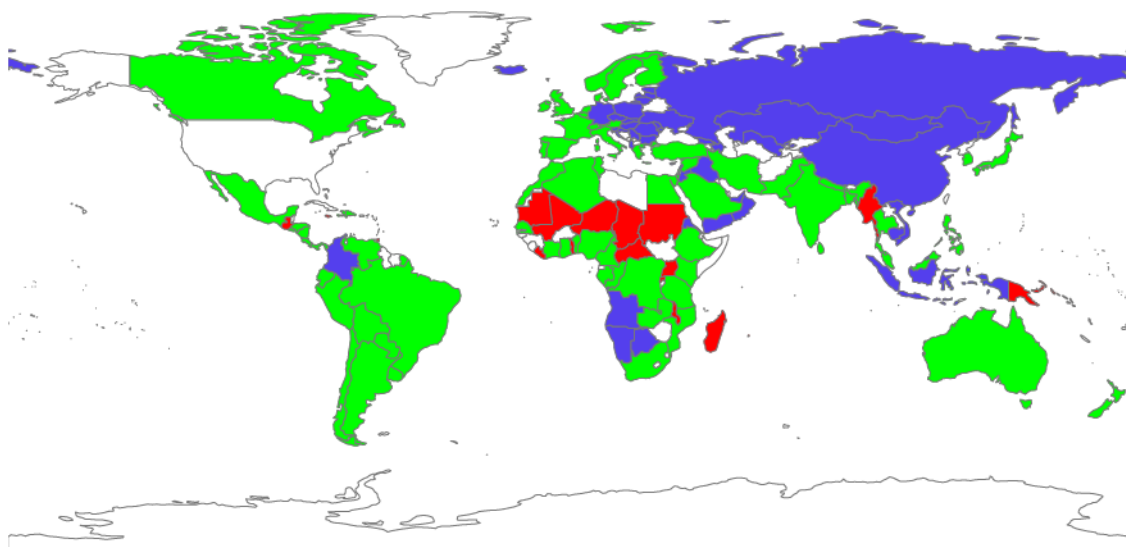
The sample of 111 countries here included is composed as such:

- **Advanced Economies** (22 countries): Australia, Austria, Belgium, Canada, Switzerland, Germany, Denmark, Spain, Finland, France, United Kingdom, Greece, Ireland, Iceland, Israel, Italy, Japan, Netherlands, Norway, New Zealand, Portugal, and Sweden.
- **Eastern Europe and Central Asia** (21 countries): Albania, Azerbaijan, Bulgaria, Czech Republic, Estonia, Georgia, Croatia, Hungary, Kazakstan, Lithuania, Latvia, Moldova, Poland, Romania, Russian Federation, Serbia, Slovak Republic, Slovenia, Turkey, Ukraine and Uzbekistan.
- **East and South Asia** (16 countries): Bangladesh, Brunei, China, Hong Kong, India, Indonesia, Cambodia, South Korea, Mongolia, Malaysia, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Vietnam.
- **Latin America and the Caribbean** (18 countries) : Argentina, Bolivia, Brazil,

Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, Honduras, Haiti, Mexico, Nicaragua, Panama, Peru, Paraguay, El Salvador, Uruguay and Venezuela.

- **Middle East and Northern Africa** (15 countries): United Arab Emirates, Bahrain, Cyprus, Algeria, Egypt, Iran, Iraq, Jordan, Lebanon, Morocco, Oman, Saudi Arabia, Syria, Tunisia and Yemen.
- **Sub-Saharan Africa** (19 countries): Angola, Benin, Botswana, Cote d'Ivoire, Cameroon, Democratic Rep. Congo, Congo, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Mozambique, Namibia, Nigeria, Senegal, Tanzania, South Africa and Zambia.

We can see that the sample is fairly balanced geographically and in terms of their economic situation. Accounting for the biases regarding the use of GDP per capita and those countries, we have tested the empirical model against a sample which does not contain any oil country, and the main results are not very much changed. The sample presented was retained so as to minimize biases caused by missing information, and so as to represent the maximum diversity in countries possible. The span of countries covered by this dataset against that of Verspagen in the original analysis is presented on figure 1.2. The countries used in this version provide a larger sample, containing more developing countries.



Key

- Green:** Countries present in both datasets
- Red:** Countries present in Verspagen's (1992) dataset but not here
- Blue:** Countries present here only
- Grey:** Countries not in either dataset

Figure 1.2: *Comparing datasets*

We discuss next the different variables which we will be using for our estimation. We intent to keep those variables as close as possible to the original ones in order to make possible the comparison between the time period of the original paper and this more recent time period.

2.1 The dependent variable: Time derivative of the technological gap

The technological gap is estimated as in Verspagen (1992) for the 1962-1985 period, that is we take the income per capita gap as a proxy for the technological gap. We calculate the gap for each year through the 1985-2010 period for each 111 countries. This rests on the assumption that technology is the main driver for economic growth and thus technological growth is directly reflected in the growth rate.

The technological gap is thus $\ln \frac{Y_{us}}{Y_i}$, i referring to the country in question, Y_i being the GDP per capita of country i . We consider the leader to be the US. There might be a problem with oil countries. They usually register high GDP per capita due to their oil production, it could even happen that the GDP per capita turns out to be higher than that of the leader. In those cases, the assumption on which we rely to use GDP per capita as a proxy for technological level no longer holds for those countries. For that reason some were excluded from the sample (Kuwait, Qatar), others were left in, though we shall keep this potential bias in mind. There is still possibility to have certain countries with higher levels of income per capita, however in our sample, those occurrences are not that frequent and concerns mainly countries with important petroleum industries⁵ and Switzerland. The use of the log function makes it so that the more behind a country is, the larger the gap, as the log function is increasing. Another useful property is that a lagging country will have a positive gap, conversely, if a country is ahead of the US, the gap will be negative. In fact, though we will refer to the US as the leader throughout this paper, it is a disputable title, given what will be later on observed regarding economic prospects of high performing countries. The notion of leader could here be amalgamated to that of a reference point in terms of technological level. When we say that countries imitate the leader, the notion should be extended to the whole technological space between the

⁵Here this happens for some years with Norway, Brunei, UAE and Iceland. The other oil countries do not observe such situation.

technological situation of country i and that of that reference point. That is the technologies imitated do not necessarily belong to the leader, rather they include all technologies which provide improvements over what is currently the level in the country in question.

The dependent variable used is the growth of the gap ($timeG$). This is a measure of its evolution over time for each country as a trend. It is computed in the same way as Verspagen, by estimating the following equation for each country i : $timeG_{it} = a_i Year_t + b + \varepsilon_i$, the time derivative, as we shall refer to it (noted $timeG$ in estimation outputs) is the a thus computed. It represents the general evolution of the country's gap against the leader over the period studied. Estimating this equation for each country allows us to extrapolate for countries with missing information (for example countries that appeared in the 1990s following the collapse of the Soviet Union) on their income per capita for given years, affecting the observation for the initial gap. The measures for income per capita is taken in constant 2005 dollars, and obtained from the World Bank statistics database. We note that for most countries, the time derivative is found to be significant; that is we reject the hypothesis that the $a_i \neq 0$ for 84 countries out of the sample of 111, which makes our future dependent variable, $timeG$, meaningful for most of the sample. Even in the cases where we cannot reject it, it would suggest that for these countries the gap does not grow as much, or that there are fluctuations within the period, but overall it ends up as small changes for the period. The goodness of fit measures (R^2) for each of the regression suggests that the model works for half of the sample (R^2 values are above 50%, the threshold is disputable). The different values of trend a_i are presented on the map (figure 1.3).

Overall, the time derivative represents the general tendency of movement of the gap over the 1985-2010 period. Looking at just the sign is not telling much, as countries can experience similar overall trend in technology gap progression, while being in very different situations. For example, Switzerland and Benin have similar time derivative (almost equal, and positive), however Switzerland will be later found to be in a position of potential leader, whereas Benin is a "falling behind" country. Further examples of this issue can be found on the map of figure 1.3, where we can clearly see that there appears to be little correlation (spatial) of the gap growth. Even BRIC countries have different type of trends with India and China catching-up faster than Brazil (lighter countries have a smaller gap growth, they are thus catching up faster) which seems to be less performant in those regards.

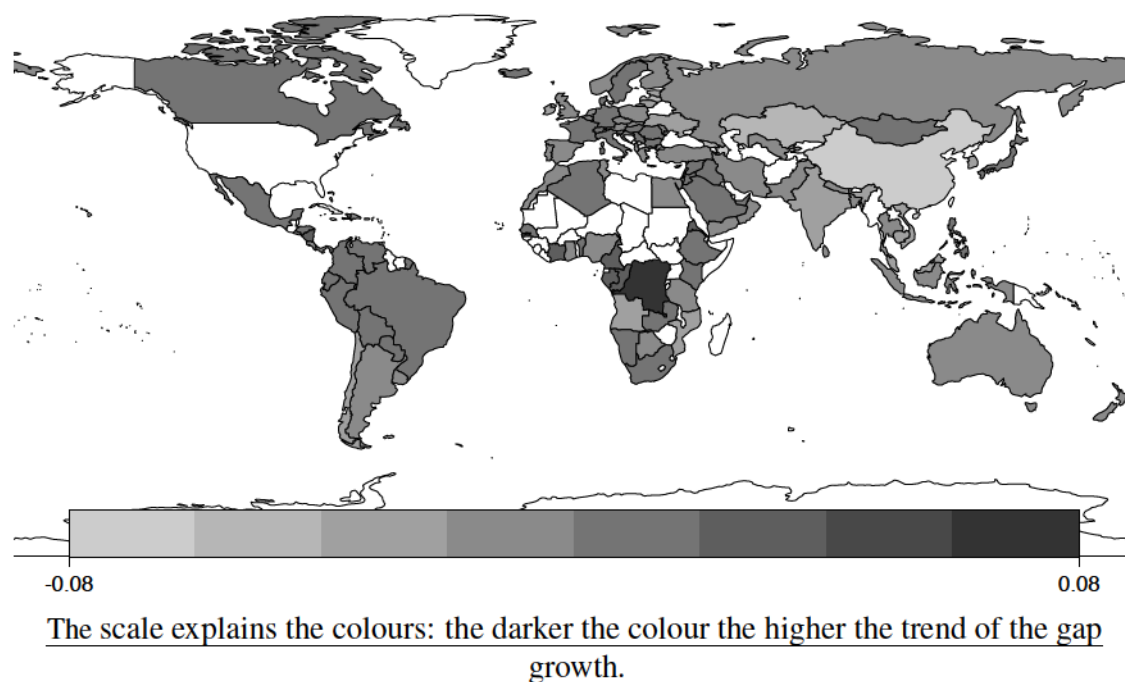


Figure 1.3: *World distribution of the trend in technological gap growth for the 1985-2010 period*

2.2 Explanatory variables

a. Exogenous research

In the original model, it is assumed that the gap between a leader and a follower grows exogenously due to different levels of research conducted and innovative output in those countries. Theoretically, this differential should be measured by taking the difference of amount of research or innovativeness. However, this remains a vague indicator (what is considered as research?. Measurement issues), and unobservable empirically. In the original model, the number of patents produced (at the USPTO) in the given period per capita was used as the measure for exogenous technological progression. In a first instance, we retain a similar indicator. The World Bank dataset has a patent variable, and is constructed similarly to the one had previously used, that is it uses patents granted in major patents offices under Patent Cooperation Treaty procedure or with a national patent office. As a side note, when the patent count is divided by the number of inhabitants, this can yield very small numbers. In order to limit this issue, we normalize the per head count at 1 for the US. We divide the number of patents of the country by that of the US. This gives a more

readable variable (noted *PAT*), and also allows us to represent the innovation variable as innovation relative to that of the leader; which is quite practical as the innovation dynamics represents the widening (or in exceptional cases of high performing countries, closing) of the technological gap just because of the technological advantages the leader has.

The problem remains the same as always in innovation economics when using patents as a measure of innovativeness. As well known by now (Pavitt, 1985; Grilliches, 1998), the use of patent data as an indicator for research output remains quite limited (i.e. not every invention is patented or patentable, bias in the choice of patent office, inventors nationality (or residency) does not reflect necessarily domestic output, etc...), however given the type of countries we are interested in, there are few other indicators which can be used.

Alternatively, we propose to study the model using a scientific publications index (noted *PUB*). This is because it provides a less biased measure, and also as tests will show, a more significant measure. The way the variable is used is the same as with patents. We take the sum of per capita publications over the years by authors from the country in question and normalized by the US value. The correlation between the patent and the publication index is of 0.36, suggesting that there is a difference between what is being actually captured by each indicator. There are still flaws (ie not every innovation is accounted for, there is bias towards the English language). We could have chosen to keep the patent variable used previously, however it has risks of yielding very small numbers, if not 0s for many countries. This publication variable is taken from the Word Bank, and comprises all publications (or share of in the case of co-authorships) by authors in a given countries in scientific journals⁶. The publications are articles from journals accounted by the Institute for Scientific Information's Science Citation Index (SCI) and Social Sciences Citation Index (SSCI).

Such indicators are slightly different from the theoretical model. In the theoretical model, this part should account for the exogenous growth of the gap, and thus ideally we should have used a "Gap" type of variable (innovation gap). The fact that we use the relative innovative output does not change much in terms of the analysis, it just affects expectations of the coefficients. Had we used an indicator in the shape of a differential between leader and follower, we would have expected the variable obtained to have a

⁶physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences.

positive correlation with the time derivative, that is the higher the differential, the faster the speed of the gap growth. Here we expect the effect of the chosen variable to be negative; that is the higher the publication count for a country, the less the technological gap will tend to widen.

We note that the following countries have a higher publication index than the token “leader”: Australia, United Kingdom, Netherlands, Canada, Finland, Denmark, Sweden, Switzerland and Israel. This opens up the question as to what actually establishes a leader.

b. Initial gap

The initial gap (noted G_0) is the technological gap (here again the income per capita is used as a proxy) at the beginning of the period studied, so here it is the gap in 1985. The initial gap is chosen in order to model the hypothesis put forward by earlier convergence literature (Baumol (1986), Abramovitz (1986)) that the further away from the technological frontier a country is, the higher the speed of catching up. Therefore, we would expect a negative sign of the coefficient corresponding to this.

Some countries retained in our sample did not exist in 1985. A virtual initial gap for those countries was computed using the least-squares model used to obtain the time derivative. Through a simple extrapolation method, the gap in 1985 for those countries i was obtained as such $gap_{1985} = \hat{a}_i * 1985 + \hat{b}_i$. This allows us to widen the sample, and include other types of countries (mainly post-USSR fall). The measurement error bias is small as it only concerns a handful of countries in an otherwise large sample. These countries are: Lithuania, Ukraine, Azerbaijan, Georgia, Latvia, Kazakhstan, Moldova, Eritrea, Croatia, Uzbekistan, Czech, Republic, Slovenia, Serbia, Russian Federation, Estonia, Yemen, Slovak Republic, Saudi Arabia, and United Arab Emirates. Most of these countries have missing information for a few years until the early 1990s, the others (such as the UAE or Saudi Arabia) only have a couple of missing information, which limits the bias of the extrapolation method⁷.

⁷We have ran the main estimation while keeping the initial gap as the first empirical observation for the whole sample, this did not affect the results significantly.

c. Education

The education variable retained is the gross primary school enrollment rate (EDU_1). The mean of this variable in this case is significantly higher than that of Verspagen (1992), however this can be explained by the use of gross rates rather than net. The gross rates account for every student enrolled in a primary school relative to the number of a children in the age class for primary school. Therefore, there could be students older than the primary school age, which can cause higher enrollment rates⁸. This was done because of higher data availability. In order not to reduce the sample too much, the indicator for this first education variable is an unweighted average of the rates over the period, this allows to deal with countries where the information was not available for given years. There are only few missing values, which should not affect the quality of the indicator too much.

There is a second variable used, it is secondary education (EDU_2). Similar methods were used, however the variable is usually found to be not significant for the model in which we are interested. Both variables were taken from the UNESCO database. One could argue that those education variables are highly correlated with one another and therefore should not be used together in a regression model for risks of multicollinearity. However, development theory would suggest that there are different uses for each variable. One captures the low skilled human capital whereas the other characterizes a higher skilled human capital. Although equation (1) contains both, we normally only consider one of the two. Tertiary education could be taken into account, however we would argue that it is more representative of a country's ability to innovate. Even though it contributes to human capital, developing and under-developed countries are more likely to need a low skilled human capital, represented by primary and secondary education educated workforce.

d. Infrastructure

In Verspagen's work, the variable used to represent the level of infrastructure is electricity capacity per head. Due to availability of data, we choose to use the per head electricity production (noted *INFRA*). The capacity refers to the potential of electricity production, whereas the "electricity production" variable reports the actual production in the country.

⁸It is possible to have higher than 100 percent enrolment rate as the rate is calculated for an age group. If older or younger students are enrolled in the school, this can lead to reporting more students enrolled in the school than the number of student in the age group.

This data is found at the World Bank. Thus we use an average over the period, which we turn into an index by normalizing at 1 for the US. Such method could give a potential bias for countries which have only recent observations (from the early 1990s). However we notice that these are developing countries and under-developed countries, and when comparing their rank in terms of infrastructure, they do not seem to experience a positive bias, their *INFRA* variable seemed coherent with their technological gap, and in line with what similar countries seemed to experience.

2.3 Observations on the data

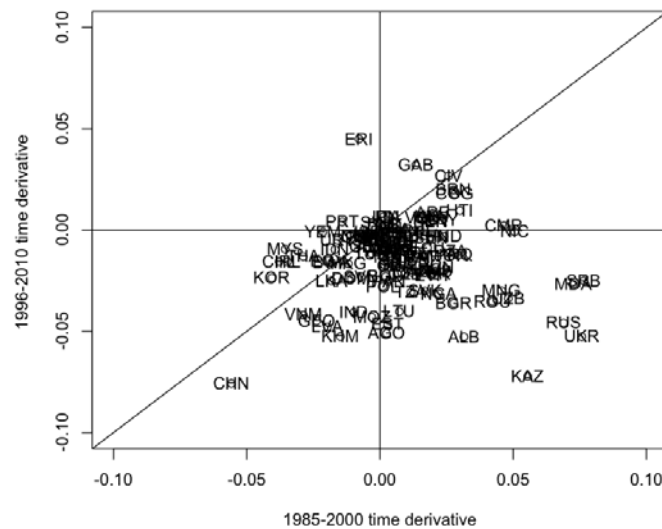
Variable	Mean	Std. Dev.	Min.	Max.	Years	N
Growth of Gap (timeG)	-0.004	0.019	-0.079	0.068	1985-2010	111
Publication	0.207	0.367	0	1.471	1985-2010	111
Patent	0.171	0.571	0	5.219	1985-2010	111
Initial Gap	1.788	1.201	-0.733	4.532	1985	111
Primary Education	100.798	13.465	48.777	145.557	1985-2010	111
Secondary Education	72.296	29.095	6.691	142.374	1985-2010	111
Infrastructure	0.28	0.36	0.001	2.093	1985-2010	111

Table 1.1: *Descriptive data*

Table 1.1 presents the descriptive statistics for the variables which will be used for the empirical analysis. All 111 countries have a value for each of the variables retained, although we note that as mentioned above certain countries have their aggregates variables formed from observations over a period starting later than 1985. This is because of missing informations in the early years, often due to political reasons (i.e.: the country did not exist then).

We can see through table 1.2 that the variables have a very low correlation with the dependent variable and are highly correlated among themselves. We note that in Verspagen's dataset, the variables experience similar relationships among themselves. The correlation among the dependent variables is to be expected given the elements measured; most of the variables pertain to the level of development in the country. Fortunately, those correlations are far from perfect, and there is probably no other variable to proxy those variables which would diminish the correlation coefficients and be as widely available

	<i>timeG</i>	<i>PUB</i>	<i>PAT</i>	G_0	EDU_1	EDU_2
<i>timeG</i>						
<i>PUB</i>	0.04					
<i>PAT</i>	-0.02	0.36***				
G_0	-0.18	-0.64***	-0.30**			
EDU_1	-0.13	0.04	0.02	-0.34***		
EDU_2	-0.20*	0.62***	0.30**	-0.76***	0.36***	
<i>INFRA</i>	0.04	0.69***	0.28**	-0.68***	0.09	0.62***

Table 1.2: *Correlation table*Figure 1.4: *Evolution of the trend within the period*

as the chosen variables. The fact that there seems to be no correlation with the chosen dependent variable is quite normal as the theoretical model chosen is not linear. The correlation coefficients are helpful for indication of linear relationship. Here, the model is built of indirect and non linear effects on the speed of growth of the gap. In that sense, finding no linear correlation comforts us in the choice of the non linear model. In linear econometrics, if one were to find such a correlation table, the estimation would certainly not fit a regular OLS model. However, we cannot infer that there is absolutely no significant effect between development variables and the technological gap's evolution; it should be quite the opposite. Using the non linear model will thus allow to look for the shape of these relationships among the variables.

Figure 1.4 represents the evolution of the trend of the gap growth within the period. We simply re-estimated the time derivative for two sub-periods (1985-2000, and 1996-2010) in order to check if the trend of the technological gap changes. Observations tend not to

be on the 45° angle line, which suggests that the trend changes for most of the countries. Regarding countries, a couple of observations can be made: In the lower right quadrant are countries which had a positive trend of the gap growth at the beginning but which became negative at the end of the period. These are mainly Eastern Europe countries which used to be in the Soviet Union. In the lower left quadrant are countries which were reducing the gap at the beginning of the period and still are at the end of it. There are mainly asian countries. Countries which lie below the the 45° angle line are countries which are improving their technological gap situation (i.e. the speed of growth is reducing), and we notice that the majority of the countries in the sample are doing so⁹. However, even though the speed of the gap is reducing, this does not necessarily mean that the gap itself is; there needs to be a negative speed of growth for this to happen.

3 Results

3.1 Estimation results

The results of the estimations are consistent with what was found for the 1965-1985 period. This is to say that the effects of the explanatory variable (and sometimes their significance) on the time derivative are of the same order. The mechanisms identified previously are still valid. For example, we can highlight the role of education on technological catching up. As a policy instrument, education is still the most prevalent one. The estimations presented in Chapter 6 of Verspagen thesis were replicated for this new dataset. While there are some differences, they do not seem so significant that no parallel may be drawn. The results of the linear specification estimation are given in the appendix, we here focus on the non-linear specification

Model estimation

Verspagen shows that the nonlinear specification is more significant than its linear counterpart. We thus turn our focus to the estimation of the non-linear model¹⁰. The estimations are presented in table 1.3 below.

⁹This might be facilitated by the fact that the American economy (our reference point) is slowing down

¹⁰For details of the method of estimation, see section A in the appendix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	timeg	timeg	timeg	timeg	timeg	timeg	timeg
pub		-0.017**	-0.017**	-0.005	-0.014*	-0.011 .	-0.012*
pat	-0.004						
g0	-0.014 ***	-0.019***	-0.018***	-0.003	-0.018**	-0.0173***	-0.014***
edu1	-0.011	-0.020*	-0.029*		-0.038**		
edu2			0.0325	26.59		-0.068**	
infra	-69.265	-67.983	-80.834	-1230			-130.2**
constant	0.011**	0.019***	0.019***	0.003	-0.015**	0.013**	0.014**
<i>N</i>	111	111	111	111	111	111	111
AIC	-587.37	-594.83	-594.13	-577.11	-572.55	-582.13	-593.69

. $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, results are rounded.

Table 1.3: *Estimations for non-linear model*

We estimated the model including or excluding certain policy parameters, though the shape of the model remains the same.

The problem with non linear estimations is that the usual goodness of fit measure (the R^2) cannot work in those cases. The reasoning behind this is that the meaning usually associated with R^2 , that is how much of the variance among observations can be explained by the model cannot apply. The R^2 must have a value between 0 and 1 and the specificities of nonlinear estimations make it so that sometimes the R^2 thus computed in nonlinear models can yield values outside of this range, making it nonsensical to attempt to interpret it. Model selection is here made through observation of significance of the estimated coefficients and reinforced through observing the AIC (Akaike Information Criterion). In theory, we should aim at minimizing the AIC. This is an indicator of loss of information, and the model with the lower AIC has a higher probability of minimizing loss of information thus indicating a better fit.

We first estimated the model retained by Verspagen and compared it with the similar model which uses publications instead patents (specification 2 vs. specification 1). This first step tells us that using publications improves the quality of the model as the patent variable has here low significance. The model with patents has a non-significant policy coefficient, be it education or infrastructure. Additionally, the AIC is minimized between those two models by using the one with publication. This reinforces our decision to use publications instead of patents as the variable to model exogenous technological

development.

Generally, regarding other specifications, the signs of significant coefficients are as expected. The non-linear estimations produces results which are consistent with the theory and hypotheses. We find that in this case that the secondary education variable is not significant and that primary education is best suited as a choice for policy parameter. We chose to exclude it because it is not significant, the sign are contrary to expectations (which would affect the pertinence of the analysis), and because it does not perform well in terms of AIC¹¹. This potentially contradicts the interpretation we made for the linear version that the standard for low level skills might have risen thus justifying the greater explaining power of the secondary education level in the first instance. In any case, the result of the non-linear estimations suggests that primary education is a better contributor to the learning capability of countries in general (as the sample includes both developed and developing countries). We opt to include the infrastructure variable, as the signs are as expected and when used solely it is found to be significant.

We choose to retain the second specification, as it contains more coefficients, even though some of them are only significant at 10%. We find that the impact of the initial gap on the increase of the gap is negative, the same can be said about policy parameters (we retain only education 1 as it is more significant), although it seems that the impact of education is more significant than that of infrastructure¹², thus underlining the importance of human capital, even if it is low skilled. Exogenous research is somewhat significant in diminishing the gap. Choosing this second specification also allows us to have a model very similar to that of the 1965-1985 period.

All in all, this gives us the following specification of the model to compute roots and check for catching-up status:

$$timeG = 0.020 - 0.017 * PUB - 0.018 * G_0 e^{\frac{G_0}{-0.020 * EDU_1 - 67,984 * INFRA}} \quad (1.4)$$

¹¹The inclusion of this variable increases the AIC, when it should be decreasing it. A model with more variables is expected to have a smaller AIC, otherwise the inclusion of an extra variable causes the model to explain less and be less pertinent. This is what is happening here for specifications 2 vs. 3. Usually the AIC may only be used to compare models with the same number of variables.

¹²We note that infrastructure coefficient has a large standard error.

For reminder, the specification found by Verspagen was:

$$timeG = 0.0149 - 0.0055 * PAT - 0.0294 * G_0 e^{-0.087 * EDU_1 - 4.5277 * INFRA} \quad (1.5)$$

We note that the coefficients may not be directly compared, this is because we use different variables; and when similar ones are used, they are not computed with the exact same method. The specification we found is not so far fetched from that of Verspagen's. Additionally, the significance of the coefficients found for the retained specifications matches that of the original analysis. This means among other things that the basic mechanisms at play remained the same over time. Also, the advantage of having similar results is that it makes both analyses rather congruent and thus open for comparisons.

Below are the plot of fitted vs empirical observations of the dependent variable, so as to give us an idea of the quality of fit (as the R^2 is not a reliable measure) of the chosen model (figure 1.5).

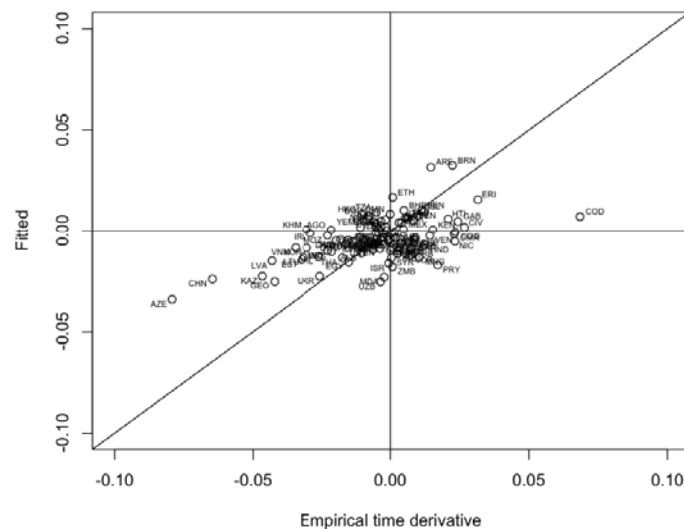


Figure 1.5: *Prediction quality of the retained model*

We find that there are a few dramatic outliers (Certain countries are (really) badly projected: Azerbaijan, China, and the Democratic Republic of the Congo.), and in general that the observations are not following the 45°line much. Rather, the fitted observations seem to be centered around 0.

The model makes an assumption that the catching-up process is the same for everyone, as pointed out by Pyka et al (2009) given the fact that the coefficients estimated are the same for any country regardless of their economic situation. In their study, Pyka et al (2009) explore the idea that different countries operate under different catching up regimes, and test what may set countries apart from one another, thus forming the “social capabilities” of countries, that is their ability to catch up. They look at threshold values for different variables and their ability to properly define those groups. They found mainly that the initial gap (measured through labour productivity) was not a good indicator, but education was. This comforts our finding that education is a significant indicator for the learning capability, and reinforce their argument that countries with higher achievements in education are going to face a different, and facilitated catching-up process than others. Splitting the sample in order to estimate a model for each sub-group accentuates the fact that the catching-up paths for LDCs are miles away from that of developed countries which are not exactly in a catching-up, but rather competing with the leader.

The fact that we have those previously mentioned outliers tends to support this argument. These are group of countries which are experiencing a very specific development pattern. In the lower left quadrant, those outliers are from (or previously from) communist economies. Those in the upper right quadrant are sub-Saharan countries. While we cannot give a precise explanation, it is certainly clear that those countries have similarities in their History which might have created specificities regarding their development paths. As the model attempted to regroup every country under one type of development dynamic, those specificities were not accounted for, and this might explain the deviations in the fitted variable.

Another way to check qualitatively the predictions of the model is to compare what happens empirically to the gap to its predicted evolution. Table 1.4 presents the number of mismatches and matches between theoretical predictions and empirical. The predictions corresponds to the sign of $-\beta_2 G_0 e^{\frac{G_0}{d_1 EDU_1 + d_3 INFRA}} - \beta_0 + \beta_1 PUB$, which tells us whether or not the effects of imitation on the speed of growth of the gap can outweigh its increase due to the advancements in innovation made by the leader (based on the initial gap). If imitation is sufficient to permit some reducing of the gap, then we would expect that at the end of the period (2010), the gap must have decreased from its original value in 1985. It would seem that only 37 observations experience a mismatch between empirical

	Empirical increase of the gap	Empirical decrease of the gap
Predicted increase	22	17
Predicted decrease	20	52

Table 1.4: *Evolution of the gap: Predictions vs. Empirical observations between 1985 and 2010*

observation and theoretical, so only 33% of predictions are not actually correct, which is arguably a rather good result considering the previous comments regarding the use of a one-size-fits-all model for a very heterogenous sample.

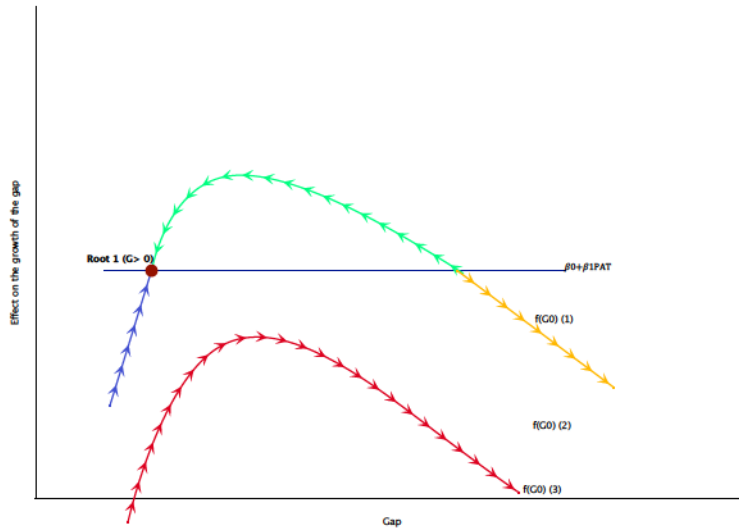
This means that even though sometimes the absolute values make it seem like there is a large mismatch between the fitted observations and the empirical ones, qualitatively, the model still works to some extent to present the trends worldwide. The mismatches could be due to drastic changes in policy, notably in innovation during the period which are not fully accounted for in the model. One example of this would be countries like Norway, Sweden or Germany which according to the model were predicted to increase the gap¹³ (up to their stable point), actually observed a decrease of the gap, probably due to their innovation capabilities. For developing countries with a similar type of mismatch, this could be explained by improved development policies. The other type of mismatch - when countries were predicted to reduce the gap, but ended up increasing it - affects very different types of countries, from highly developed ones like Canada or New Zealand, to emerging powers like Brazil or South Africa, or even really lagging countries like Mongolia. The explanation for developed countries is that there is a more competitive dynamic with the leaders, whereas for the developing and least developed, it could be that there is a failure to keep up during the studied period, and reducing the gap might actually take longer than predicted.

3.2 Analyzing the catching-up status of countries

The estimation result allows us to see which countries are catching-up, falling behind or falling behind with no chance of catching up. The difference between the last two categories refers to chapter 5 of Verspagen's thesis (1992), which explains that based on a country's characteristic (here the explanatory variables), we can tell if there exists a

¹³In the case of Norway which had a negative initial gap, an "increase of the gap" means that they would be losing some of their lead over the US.

possibility for that country to catch-up. Considering the last specification of the model ($\dot{G} = \beta_0 + \beta_1 PUB + \beta_2 G_0 e^{\frac{G_0}{d_1 EDU_1 + d_3 INFRA}} + \varepsilon$), we look at the equation $\beta_0 + \beta_1 PUB = -\beta_2 G_0 e^{\frac{G_0}{d_1 EDU_1 + d_3 INFRA}}$ presented in section 1, which assumes the growth of the gap to be null. With the parameters we estimated, we can find the point where the gaps stops growing for each country (referred to as root 1) if it exists given their own characteristics.



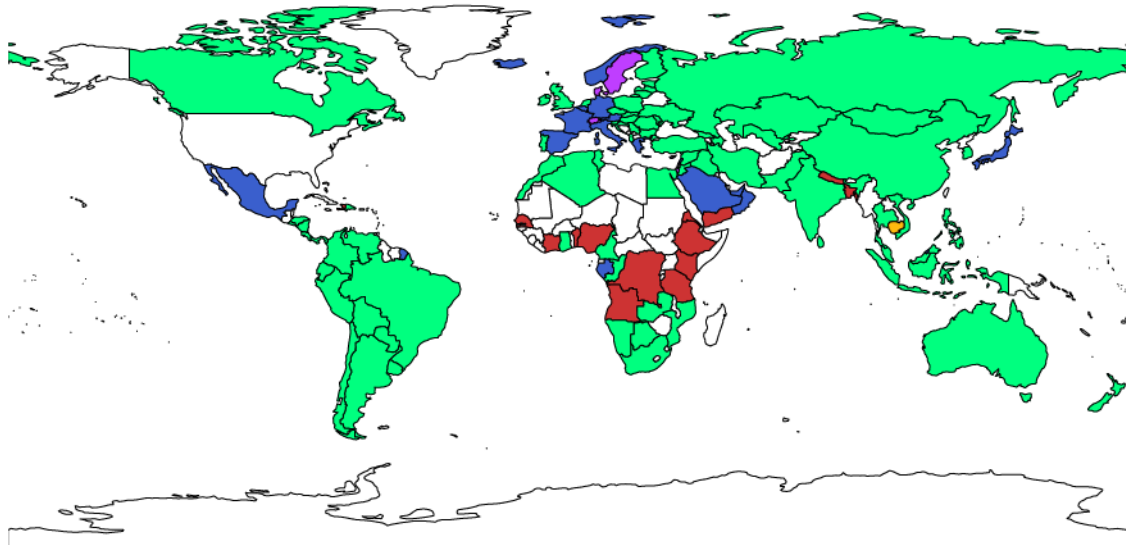
- Blue:** Follower countries which are going to increase the gap up to their stable point.
- Green:** Catching up countries which are going to decrease the gap up to their stable point.
- Yellow:** Falling behind countries, with possibility of catching up
- Red:** Countries falling behind without possibility of catching up
- Not represented here:** Countries predicted to outperform replace the leader

Figure 1.6: *Catching-up status analytically*

1. We compute the difference $-\beta_2 G_0 e^{\frac{G_0}{d_1 EDU_1 + d_3 INFRA}} - \beta_0 + \beta_1 PUB$
 - if it is ≥ 0 , then we know that the country is in a catching up phase (the green curve in figure 1.1 is above the blue line), their gap will decrease and converge towards root 1 (countries in green on figures 1.6 and 1.7).
2. If the difference is negative, then we check if there is a root by solving the equation for G_0 ¹⁴.

- $\ln\left(\frac{\beta_0 + \beta_1 PUB}{-\beta_2}\right) = \ln G_0 + \frac{G_0}{d_1 EDU_1 + d_3 INFRA}$

¹⁴The value of G_0 for which this equation is solved is the root. The root is not an initial gap.



Key

- Purple:** Countries predicted to outperform replace the leader
- Blue:** Follower countries which are going to increase the gap up to their stable points
- Green:** Catching up countries
- Yellow:** Falling behind countries, with possibility of catching up
- Red:** Countries falling behind without possibility of catching up

Figure 1.7: *Catching-up Status*

- This can be solved for G_0 using a Lambert W function¹⁵, this will give us the smallest root (root 1 on figure 1.1)¹⁶:

$$- \text{root} = (d1EDU1 + d3INFRA) * W\left(\frac{-\beta_0 - \beta_1 PUB}{\beta_2 (d1EDU1 + d3INFRA)}\right)$$

3. If there is no real root, then we know the curves never cross, thus as it stands, the country has no hopes of catching up, and will fall behind. (Countries in red on figures 1.6 and 1.7)
4. If there is a root, the country could in theory catch up:
 - If the difference computed in step 1 is negative and $G_0 > \text{root}1$, then the country is diverging and falling behind, even though it has the possibility of catching up. In our results, only Cambodia was in this situation. Graphically, it means that the initial gap is situated to the right of the second intersection (Countries in yellow).
 - If the difference computed in step 1 is negative and $G_0 < \text{root}1$, then the country will increase the gap up to a stable point. The problem is that we cannot at

¹⁵Inverse function of $f(z) = ze^z$, see Corless et al. (1996) for more explanation

¹⁶ W function can yield two results, we use the principal branch of the function as it will give us the leftmost root, ie the point of convergence.

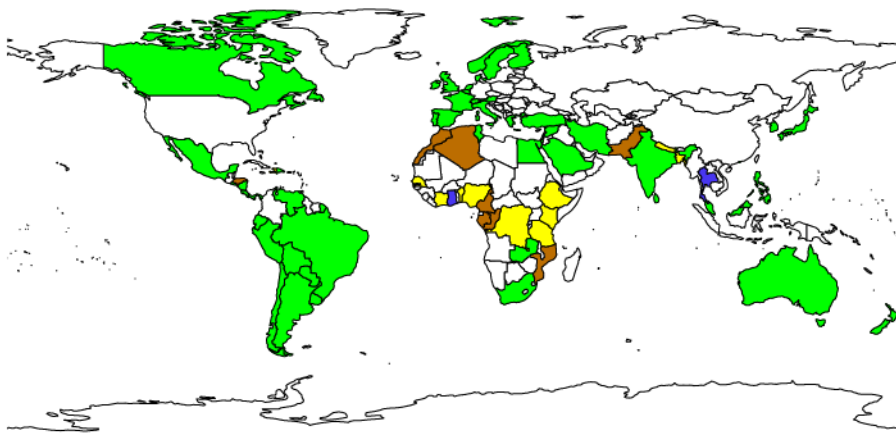
this point speak of catching up. The initial gap in those cases was relatively low, and to reach the stable point, the gap had to increase. These cases thus reflect developed countries, which are direct competitors to the leader. This is interpreted by the idea that the country has no more technology to imitate, and the only way it can progress is by conducting further innovation, thus playing on the left hand side of the equation which characterizes exogenous research. These countries are thus not exactly catching up, they are competitors to the leader which without innovation will only fall behind. They have basically reached a point where imitation is not sufficient anymore. Some developing economies also fall in this category. They have a similar explanation, they have exhausted their imitation potential as dictated by their characteristics. In those cases, it is not that they have nothing to copy anymore, but rather that they do not possess the capability to imitate the remainder of the technology. They are represented in blue on figures 1.6 and 1.7.

5. There is a last case to account for, it is that of countries where the root is negative. This means that for those countries, the stable gap point is a (negative) gap in which they are leading over the leader. This is because they had a low gap to begin with (sometimes even negative), and on top of that, they have a high level of research, which tells about their ability to innovate to be higher than that of the token leader. In our results, Denmark, Israel, Sweden and Switzerland are in this case (purple on figure 1.7). In theory, this implies that they are on the way to become the technological leaders.

Figure 1.6 above gives the graph from figure 1.1 with the colours used in figure 1.7 so that to give an idea of where countries fall analytically. Plot 2 in Appendix D shows for every country the imitation against innovation effects, giving numbers to this dual dynamic.

These results are static. We obtain those stabilization of the gap results if there are no changes in policy or research efforts. Nevertheless, we can still trace some evolution, given the fact that we have consistent data and results with that of Verspagen, we can compare countries' situations from one period (1965-1985) to another (1985-2011). This is presented in figure 1.8. The description of statuses originally used is however less precise, that is we only have three categories, against the five we had drawn in our analysis. Here

countries can either be catching-up, falling behind with hope of catching-up or without possibility to do so. Green countries are those which remained in the catching-up category (though we cannot tell if the situation improved or worsened). There is little to be said about this, if not that the expected developing and developed countries remained generally the same. Gulf countries, by virtue of their high income per capita end up in the developed world, although their levels of research output could be disputable. We can also see that certain countries (yellow ones) remained in their most precarious situation, these are the usual suspects, sub-saharan Africa, Haïti and the poorest south Asian countries. The countries for which we have data (Thailand, Ghana in blue) and that had possibility of catching up in the first dataset, actually did so; they made sufficient efforts to catch-up. Additionally, we can notice that some countries seem to have made significant effort and deviated largely from their diverging path into one that is catching up (brown countries). This concerns mainly northern Africa.



Key

- Green:** Countries which kept their catching-up status
- Brown:** Countries which went from falling behind without possibility to catch-up to catching-up
- Blue:** Countries which went from falling behind with possibility to catch-up to catching-up
- Yellow:** Countries which remained falling behind without possibility to catch-up

Figure 1.8: *Evolution from the 1965-1985 dataset*

3.3 Further analysis

The three categories classification used by Verspagen is insufficient. The problem is that when analysing technological gaps it is difficult to put India in the same category as

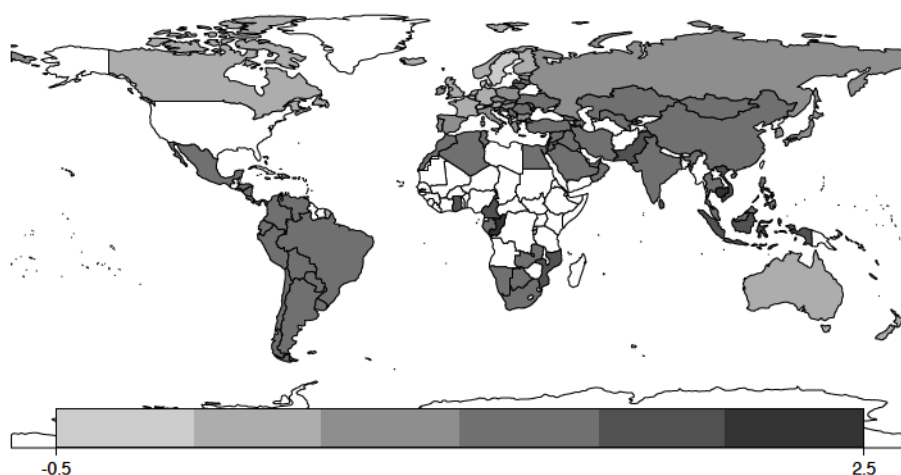
France. Although they are both technically behind the chosen leader, the challenges they face in terms of catching up differ. As we established it, a discrimination should be made according to the place of the initial gap with regards to the root. Although the point is to stop the gap from growing, India will do so by imitating some more, whereas France will do so because they reached a point where their innovation has become insufficient in comparison to that of the leader, and they cannot rely on imitation solely as it will only lead them further behind to the point where the gap stops growing, though it will increase first. This goes along with the remark made in section 2 (figure 1.3) regarding the fact that the growth of the technological gap does not suffice to qualify the catching up state of a country. One may suppose that truly understand the effects, they should take into account the initial gap, the speed of growth and the expected stable point (the root).

It is however important to keep in mind that in this study, convergence, in its traditional definition, implies that the countries make sufficient efforts to move towards a point where not only the technological gap stops growing, but also where the gap is 0. This implies that the efforts made by a country make it so that the root has the value of 0, so that the stable point is where the countries have converged durably. It is when structural changes are brought forward that countries can modify their catching up path (going back to figure 1.1, this implies that curves are shifted to bring the stable point (root 1) to the left). There are in theory two ways to achieve this, either by using policy variables to improve learning capabilities or to improve innovation performances (which are exogenous, and mostly achieved by the private sector). It is once those characteristics have reached the level of the leader, if they ever do, that we may consider the technology level to be truly caught up.

Both innovation and imitation are important for a country to have a prospect of ever reaching this point.

The oddities that are the cases of the UK, Canada or the Netherlands (which on figure 1.6 end up in a similar category as India) can be explained by looking closely at the numbers. They all have high research output, as a result their root 1 is really close to 0 (figure 1.9)¹⁷, which means that in theory we expect that these countries, once their gap stops growing, will have actually converged towards the leader and will not need much

¹⁷See also appendix C for complete sample list and the roots' actual values.



The lighter the colour, the closer to 0 the predicted stable point (root) is. The roots have a value between -0.302 to 2.48.

In white are countries which do not have a stable point, or are missing from the database

Figure 1.9: *Countries stable points*

further efforts to be mathematically equal to the level of the chosen reference country (here the US).

These examples help explain the comment made above that stopping the growth of the gap can mean very different things for different countries. For really technologically advanced countries (Switzerland, Sweden) reaching that stable point means that they outperformed the leader, for others like the Netherlands, it means that they are reaching levels equivalent to that of the leader.

However, for other developing countries, for example India, the gap point at which it stops growing is far from 0, implying that although the gap will stop growing, it will nevertheless remain quite high if no further efforts are made. This all in all is reminiscent of conditional convergence theories: similar countries converge (meaning their root 1 are close to one another), for highly developed countries, this implies that they belong in the same convergence group as the US; for other countries, if they have their technological gap stable point close to other countries, then these countries will form groups and converge among themselves. Additionally, the position of the root is itself quite telling, as it looks at where a country will end up if no changes are made. Therefore it is a necessary add-on to the analysis, it helps understanding cases like that of the Netherlands as we can see that their convergence point lead to a very close gap. To give an idea of sizes of the root, we are reminded that the gap is computed as $\ln \frac{y_{US}}{y_i}$, so if the root (which is a gap) is close to 0, this implies that the two income per capita are more or less equal. If the root is close to 1,

then this implies that the income per capita of the US is at least 2.7 times greater than that of the country (at the stable point) .

Figure 1.10 shows that there is apparently a positive correlation between the root and the initial gap, suggesting that most advanced countries should have a smaller root. A smaller root implies that the point at which the gap will stop growing will be closer to 0. This means that the characteristics of the country are such that its technological potential is similar to that of the leader. In case of a root of 0, the country will have totally caught up to the leader. A negative root means that the potential is greater than that of the leader.

This shows that the analysis should not be limited to just one criteria, and we can get much more precise information on actual catching-up trends and mechanisms from this seemingly simple model.

With all this in mind, we may make the following remarks.

3.3.1 Innovation dynamics

The first plot on figure 1.10 divides the sample in two main groups: those with significant innovation capabilities, and those with relatively inexistent ones. For those with existing innovation capabilities, there is a negative relationship between innovation and the root point where the gap stops growing. This means that the larger the innovation level of the country the closer to the technological frontier the country will be when its gap will have stopped growing. For some very innovation intensive countries, this root point is negative, suggesting that at the end of the period, those countries will have outperformed the reference country.

We note that countries with no innovation will at best reach a gap stable point of around 1. This means that if a country is solely relying on imitation, the innovation effect will take its toll on the gap's evolution, as the countries will be constantly outperformed by countries with technological levels closer to that of the frontier. The only countries which go beyond this threshold are those with a minimum of innovation.

This brings us to the first proposition:

Proposition 1.1. *Innovation is the key to ensure that countries will ever make significant progress towards the leader.*

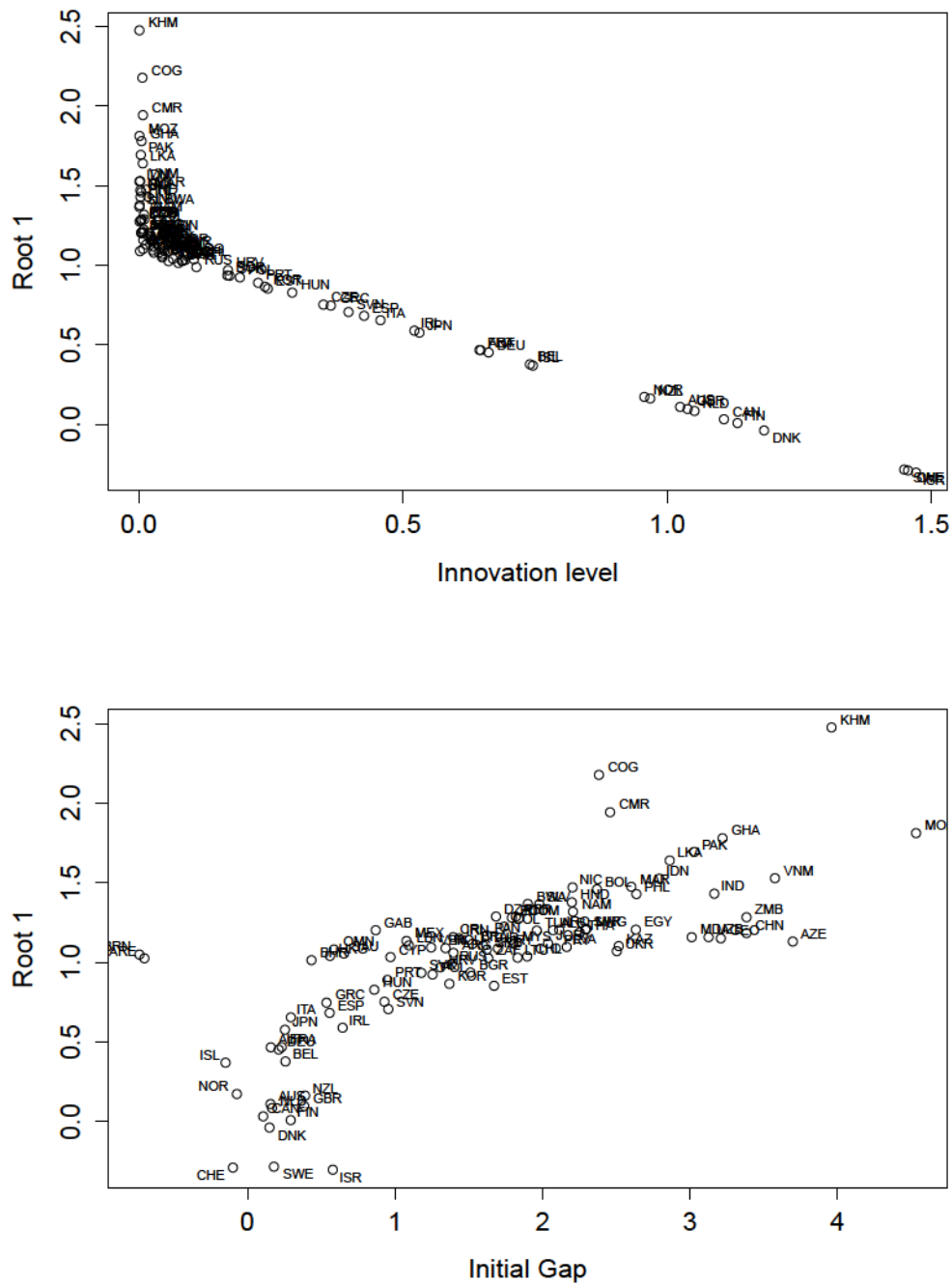


Figure 1.10: *Plotting stable points against level of research and initial gap*

Additionally, on figure 1.10, we can observe that countries with no innovation have a wide a range of possible stable points, from as low as the previously mentioned threshold to as high as 2.5. The initial gap can explain in part those differences, but not only, as the second plot shows that countries with a similar initial gap can have different root points. As such, we can formulate a second proposition linked to the first:

Proposition 1.2. *Innovation, or lack thereof cannot solely explain why countries are going to stay far behind.*

Therefore, we look into the second technological dynamic: the imitations.

3.3.2 Imitation dynamics

Generally, the higher the initial gap, the higher the expected stable point. This relationship is however not linear, thus suggesting that the effect of imitation can be important in helping countries closing their gaps.

The imitation effect on the growth of the gap is here modelled by the part of the equation $\beta_2 G_0 \exp(\frac{G_0}{d_1 \text{edu} + d_2 \text{infra}})$. As mentioned in section 2, we expect β_2, d_1 and $d_2 < 0$ (so $d_1 \text{edu} + d_2 \text{infra} < 0$), which were confirmed empirically.

When looking at the group of countries which have no innovation, some of them have a root point around 1, whereas others observe a much higher value than that this, regardless of their initial gap. That is some countries can have a very large initial gap, like Zambia, and end up at a stable point of value around 1, whereas countries like Ghana, with a similarly large initial gap can have a stable point value around 1.6. Both are similar countries with regards to their innovation levels, so it must be the imitation which makes the difference. Having similar gaps means that they both have the same potential for innovation, it must be that Zambia is more efficient at capturing actual spillovers, therefore benefitting more from imitation. As a result, if nothing changes, in the longer term, Zambia will have a lower technological gap than Ghana. We can consider that those countries are in their early development stage due to their high gap and non-existent innovation. As Zambia seems more effective in their imitation, they will ensure themselves a greater chance at building their technological stock, which in the future can turn out to be an advantage for establishing strong innovative capabilities. This gives us proposition 3.

Proposition 1.3. *The effect of imitation can be crucial for countries which are farther*

behind.

As mentioned in section 2, the way the imitation dynamic is modeled is done so to represent the conflict faced by countries regarding potential vs actual spillovers received. In short, a greater gap increases the potential of imitation (as there is a larger knowledge base on which to draw), however the backwardness caused by important technological gap make it more difficult for countries to achieve this potential.

We can look at the marginal effects of each variable. First, for the policy variables, for any positive G_0 , that is the country is a follower, then all things equal, an increase in any policy variable will slow down the growth of the gap through the imitation effect. This is because those policy variable intervene solely in the learning capability which increases with greater efforts in education or infrastructure policies. There is unequivocally no adverse effect on the imitation effect.

It is a bit more complicated for the role of the initial gap. For $G_0 > 0$, the imitation effect on the speed of growth of the gap is necessarily positive. One of the hypothesis of the model was that a higher gap should mean that there is more to imitate and thus the speed of growth of the gap should decrease with the initial gap. We find that this is true only if $G_0 < -(d_1edu + d_2infra)$. This threshold indicates a maximum acceptable gap which verifies this first hypothesis. Beyond this, for a similar policy effort, a higher gap cannot permit faster imitation.

This is because the learning capability which dictates the success of the imitation process is dependent on the initial gap. The learning capability is modeled by the exponential component $\exp(\frac{G_0}{d_1edu + d_2infra})$ which is always < 1 for a positive initial gap. It thus represents the proportion of the gap in technology which is available to a country. This proportion increases for an increase in policy (all else equal, $G_0 > 0$); and decreases for a higher technological gap (all else equals, $G_0 > 0$).

This means that a country with a lower initial technological gap will require less education or infrastructure to assimilate the quantity of knowledge available. There could be two explanations: the low gap means that it is technologically advanced and thus it has the right abilities to imitate successfully; or there is less left to imitate, and as such it would require a smaller policy effort. Conversely, a country with a high gap would require a high level of education and such as it does not dispose of the right skills to imitate, or the gap is so large that a stronger policy effort is required to acquire the technology. In any case

this help show that the initial gap also serve as determinant of learning capability: it acts as a proxy for the level of technology available in the country and as a point of reference regarding which efforts are necessary.

Going back to figure 1.10, the relationship between the root point and the innovation level when it is different than 0 is seemingly very linear. Countries which innovate tend to have for the majority a relatively small initial gap¹⁸. This means that for those countries, little efforts are necessary for them to exploit the technology available to the maximum. For such relatively technologically developed countries, what makes the difference in terms of root point is solely the innovation level. Figure 2 in appendix D corroborates this, as countries for which the innovation effect increases less the gap (i.e. countries with innovation levels different than 0) tend to have similar levels of the imitation effect, in general.

Figure 11 plots the imitation effects calculated as $\beta_2 G_0 e^{\frac{G_0}{a_1 EDU_1 + a_3 INFRA}}$ against the initial gap. The results illustrate clearly the analysis made so far regarding imitation dynamics. For most countries with a positive gap that stays “reasonable”, we find that there is a negative linear relationship with the initial gap. The larger the initial gap (up to a certain level, threshold around 1.5), the more imitation is able to reduce the speed of growth of the gap. These countries can be regrouped as countries which are not so much lagging, and which have the appropriate amount of development policies to exploit the gap in knowledge.

Beyond the threshold, we can observe two types of behaviour for the imitation dynamics. For one group of countries, this relationship remains linear, that is the high gap can still be efficiently exploited and the impact on the speed of growth of the gap is as such more pronounced. This group contains countries like China, Latvia, Paraguay, Georgia, Ukraine, or Uzbekistan. It is difficult to place a label on those countries, though some seem to have been under communist regime in the past. For another group of countries, we can find a U shape in the impact of imitation, thus reflecting the duality of effects in the dependence on the initial gap. Those countries, which are for the majority African countries but also include some large Asian economies like India, Indonesia or Vietnam, a larger gap does not translate into a larger impact on the speed of growth. Rather, the larger those gaps get,

¹⁸It is also highly likely that those countries are used to innovating, and as such their technological abilities are already quite high, thus facilitating imitation and innovation.

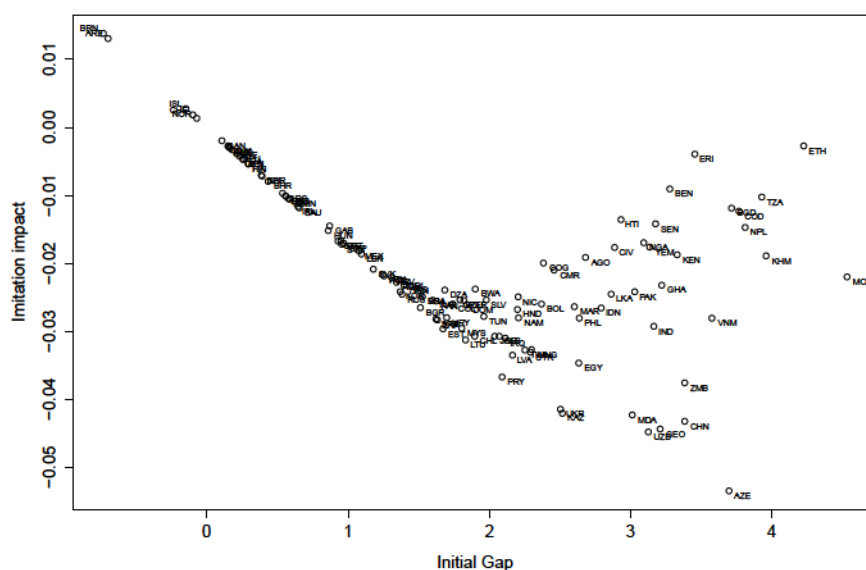


Figure 1.11: *Imitation impact on the speed of growth of the gap against the initial gap*

the more the imitation impact is reduced, thus indicating that this group of countries does not give sufficient efforts to properly exploit the amount of technologies available. Their technological level is too backwards and therefore, to benefit fully from this larger pool of technologies, a higher learning capability is necessary.

The analysis illustrated by the empirical observation on figure 1.11 brings us to the fourth proposition:

Proposition 1.4. *For a higher gap to translate into a stronger imitation effect, there needs to be sufficient and efficient policy efforts depending on the gap.*

As a side note, we have centered most of this study around the importance of the root, or stable point of the gap. It should be noted that there are countries which are so far behind that they do not present a possibility of ever reaching a stable point, and for which the gap is expected to forever increase, should no other efforts be made. These countries are mostly sub-Saharan countries (in red on figure 1.6). The case of Thailand (yellow on figure 1.6) is also not explicitly discussed, this country has the possibility of catching-up, that is reach a stable point, but in its current situation the gap is predicted to increase indefinitely as well. These countries have insufficient capabilities, and for them to stop the gap from growing more, they need to undergo some structural changes, just like other countries but with the goal of reversing the trend they are on. According to the model, this could be done through improving either innovation or imitation capabilities. However, since they

have such low learning capabilities which prevent them from imitating sufficiently to stop the growth of the gap, it is not realistic to expect that they will improve on their situation by innovating. If they do not possess basic levels of education and infrastructure, it is hardly likely that their innovation will permit them to outperform that of the US. Therefore, they must improve first on their learning capability (education and infrastructure), which will make them more efficient at imitating. They will join the ranks of other catching up countries, where the question of reducing the gap will be that of the cases discussed above.

3.3.3 Countries with a negative gap

In our sample of countries, we have mentioned before that some countries observed a negative gap. This technically means that their income per capita is larger than that of the US. As we chose to use this gap variable as a proxy for the technological gap, countries with a negative gap are technologically more advanced than the US. In terms of interpretation, we chose the US as a technological leader, though truly they are a technological reference point, this is to allow countries to outperform them technologically. Their leading position is certainly a definitive one.

The way the model is built can prove to be challenging for interpreting the case of those negative gaps countries. As a reminder, in our sample countries with a negative initial gap are: Brunei, the UAE, Iceland, Switzerland and Norway. With the exception of Switzerland, those countries have a strong petroleum industry which explains their high GDP per capita, meaning that their economic performances are not necessarily driven by innovation. Another limit of the model posed by those countries is the way imitation works.

With a negative gap, $\frac{d \text{time}G}{dG_0} < 0$. As the only part of $\text{time}G$ that depends on G_0 is the imitation part ($\beta_2 G_0 \exp(\frac{G_0}{d_1 \text{edu} + d_2 \text{infra}})$), we can see that a higher lead of country i (so as G_0 decreases, or $|G_0|$ increases for $G_0 < 0$, all else equal), leads to faster speed of growth of the gap in the US' favour, that is either the US is closing in on this lead, or country i is falling behind, losing some of its edge. The overall results still depends on the innovation.

With $G < 0$, $\beta_2 G_0 \exp(\frac{G_0}{d_1 \text{edu} + d_2 \text{infra}})$ is positive, meaning the imitation effect here increases the speed of growth of the gap, where it was reducing it for countries behind the US. At first sight, this may have a logical explanation. If a country is a technological leader over the frontier defined by the US, then the US has more to learn from this country

than the other way round. Imitation will thus be done by the US, so the imitation effect works in favour of the US rather than that apparently leading country. The higher the lead of country i , the more the US has to learn from them, thus the imitation effect has a greater impact in the cases of higher leads. The limit this interpretation poses is that what is supposedly being imitated by the US would be captured through the learning capability of country i : the loss incurred by i on their speed of growth of the gap (here their speed of growth of their lead over the US) due to imitation is $\beta_2 G_0 \exp(\frac{G_0}{d_1 \text{edu} + d_2 \text{infra}})$. $\beta_2 G_0$ can apply for both the US and country i , however what we have referred to as the learning capability $\exp(\frac{G_0}{d_1 \text{edu} + d_2 \text{infra}})$ is specific to country i , since the education and infrastructure parameters are measured for that country in question (though *infra* is normalized based on the US' value which is less problematic). So we would be saying that the amount of knowledge the US is gaining through imitation depends on the gap between those countries (logical), and on the learning capability of country i , where throughout the paper, for other countries the amount imitated depends on their respective capabilities.

This problem might be tackled by looking at the model in a different perspective. If every country is in theory able to innovate, then every country should be allowed to imitate. As the US innovates, then any other country, including those with a leading gap, should be able to imitate (depending on their abilities) these new technologies produced, despite the fact that they seem more advanced on the technological spectrum.

The fact that country i is ahead, means that the net effect of imitation is favorable to the US, as the US has more to imitate than country i . Country i 's "learning capability" is still an indicator for how efficiently it is able to imitate from the US, and thus how "resistant" they are to the imitation threat posed by the US. $\beta_2 G_0 > 0$, so a higher $\exp(\frac{G_0}{d_1 \text{edu} + d_2 \text{infra}})$ means that more will be imitated. Appendix B shows that in the case of $G_0 < 0$, the formerly known as learning capability decreases with any policy variable, but increases as the lead of country i increases.

In the present case, it would thus mean that having a large lead can be a danger in the imitation sphere, as there is less a country may copy, and more others get to work on. If a country has a large lead and has made strong policy efforts then the net imitation effect is diminished as they are more "resistant" to the US' imitation, because they themselves have strong abilities to learn from the innovations of others. This also allows to deal with the case of countries with high GDP per capita solely due to their strong petroleum

industry, such as some Middle-East countries. Their abilities (defined by policy variables) remains small, so they cannot benefit efficiently from the innovations produced by others, and all the while having low innovation capabilities themselves. Though they enjoy a high lead at first, their stable point is that of a positive gap, suggesting that they will fall behind. This conveniently illustrates the fact the their lead measured through GDP per capita is not representative of their technological level, and that whatever lead they enjoy is not permanent. In a way, the imperfection of this chosen technological level indicator is corrected by the model itself.

The term learning capability is not perfect here to describe the imitation dynamics in those cases, mainly as it is read differently than in the “normal” case where $G_0 > 0$. It does not translate exactly how much is being learned by country i , but rather how well is country i able to limit the catching up of the US’ technology by country i on learning. That being said, the idea conveyed by proposition 5 could still apply in the $G_0 > 0$ case, where net imitation is favorable to the follower country. As follower countries still have the ability to innovate, the US still has the possibility to imitate them. As such, the special cases brought forward by countries with negative gaps bring us to the fifth proposition:

Proposition 1.5. *The imitation effect may be reinterpreted as the “net imitation” effect which corresponds to the increase or decrease in growth of the gap due to the combined effects of imitation of both the country in question and the referring country.*

Proposition 5 thus captures this idea that the part of the model which represents imitation can be interpreted just like innovation dynamics in the model: there is a competition between country i and the reference country regarding technological gains through imitation.

We have here a leader and close follower dynamic: two countries close together at the technological frontier would be constantly fighting for the top spot by benefitting from imitating each other’s innovations. The country in the lead needs to not rest on their laurels, and keep developing their capabilities, because as innovation continues elsewhere, they stand to lose due to both effects.

On the left side of the plot in figure 1.11, we identify two small sub groups. They both had a negative initial gap, so it is expected that the US (our reference country, also identified as the leader) has the upper hand when it comes to imitation. As such, for those countries, imitation increases the speed of growth of the gap, because it is the US which

benefits from their lead. Countries like Iceland, Norway or Switzerland experience less loss in comparison to the other group made up by Brunei and the UAE which are countries that built their economies around the petroleum industries¹⁹. We could argue as before that the impact is less mitigated for countries like Brunei or the UAE than for the other group, not only because they have a higher lead over the US, but also because they do not possess a strong learning capability (see also plot 1. in Appendix D) like Norway and are therefore less able to absorb technologies from competing countries, making their “net loss” due to imitation far more pronounced. We support this argument by looking at their root point in figure 1.10, which seems to confirm this long term result: they may have at first sight a strong lead economically, but as they will evolve through time, not only will their lack of innovation push them behind, so will their learning capability, which is not on equal terms with that of their competition.

4 Conclusion

This paper presents an attempt to replicate a model which initially covered a dataset spanning the years 1965-1985. As we analyse what happened in the following 25 years under the similar framework, we are able to identify some mechanisms and dynamics which will serve to set one of the main premise of the work ahead.

The sample of countries chosen is highly heterogenous, as such the idea of processing and analysing their corresponding data under one unique framework could at first glance seem to be quite a dubious endeavour. However, despite some imperfections which are to be expected given the type of countries involved in the study, the overall results seem quite consistent with reality and with expectations.

The work done in this part helps us understand the main trends in catching-up processes through a simple model. It brings forwards two main points: We are able to trace the evolution of countries’ general technological levels across two long periods, and it has provided us with a means to observe the interactions of innovation and imitation processes in a leader-follower configuration.

One of the limits of the method chosen is that we work with aggregated values for

¹⁹Norway and Iceland also enjoy a strong petroleum industry, though their development level when accounting for education and such is much stronger, which places them in a different category than the UAE or Brunei/

a rather long period, which does not necessarily accentuates the considerable progress made by some emerging economies, mostly in innovation. This is for example the case for India and China, which in the very recent year have experienced a considerable spur in innovation, as measured through patents by Godinho and Ferreira (2012). As the sample concerns a very long period, those efforts are highly underrepresented. The model shows predicted trajectories over the period. It is very possible that those trajectories evolve over time, especially when shifts in technology policy intervene. The econometric methods used did not permit us to obtain results over shorter sub-periods, which would have allowed us to track changes in catching-up trajectories more dynamically.

Another limit which can offer a perspective of refinement of the model is to better account for the cases of changing leaders. As we mentioned in the last section, the model does not clearly represent the imitation dynamics from the leader's (or reference country) point of view. The model predicted that some countries by virtue of their high innovation capabilities will be able to not only catch up with the US but also outperform them. That does not mean that the new leader stops imitating. Rather, they enter a phase of competition between each other on both innovation and imitation. A country which has reached the technological frontier can still learn from others, and this could benefit from being more clearly represented theoretically.

For developing countries, two main conclusions become apparent. First is the importance of building appropriate capabilities to facilitate imitation. Imitation is a main driver for catching-up especially in the early phases of development. Countries which are strongly lagging behind need to make sufficient efforts in order to hope to start their catching-up process, otherwise the possibility of falling behind is all too strong. Secondly, when countries have used up their potential for imitation, it is not likely that they will be truly caught up to the frontier. As advanced countries keep pushing the technological frontier further, developing countries that are stuck in an imitation mode for their technological development can only hope to maintain a constant gap from the frontier. What allows countries to move beyond this constant gap is the development of their own innovation capabilities. We found that countries which have a minimum of innovation have systematically smaller gaps with the frontier than those which do not. Innovation is therefore a key for the development of countries which hope to ever rival advanced economies. For the work ahead, these findings regarding the importance of innovation

are highly relevant. As we find that imitation is not sufficient to allow for a long term development perspective, the factors which facilitate innovation are of interest for the study of countries' development.

Among the many factors possible, the one on which we will center our analysis is international intellectual property rights. Mainly, on one hand, one of the motives of setting up IPRs in innovation economics is to serve as an incentive for innovation. On the other hand, IPRs can also serve as barrier to technological development through imitation. This duality in the effects of the IPR factor on innovation introduces the main topic, that is how, through their effects on innovation and imitation, can IPRs impact the development of countries. This chapter emphasizes the roles of both innovation and imitation for technological (and by extent economic) development. The fact that IPRs can affect both makes it a prime factor to analyse.

Chapter 2

Overview of the technological transfer channels to developing countries

1 Introduction

In the previous chapter, we have shown that the catching-up process of developing economies was highly dependent on the imitation dynamics that helps push the countries forward in their development process. This means that developing countries rely on the technological advancements made by developed countries to progress on their own technological path. This suggests that there is some interaction that takes place between developed and developing economies allowing for the southern countries to be exposed to and obtain foreign technology, thus permitting this transfer of technology from the North to the South. In this chapter, we are focusing on understanding how these interactions work through an overview of the empirical and theoretical literature. The purpose of this task is to provide us with a description of links between North and South as we aim to uncover the mechanisms which make those transfers of knowledge possible. In the literature, as mentioned by Saggi (2002) in his survey, there are two main channels of transfers: Foreign Direct Investments (FDI) and trade. Within those two channels we find that the results regarding the efficiency of technological transfers are contrasted. This is precisely what draws our attention, as we try describe the mechanisms underlying the transfers and understand what conditions make them more or less successful in aiding the technological development of southern countries. Surveys on transfer channels argue that more channels can be identified through for example the international labour mobility, though as Saggi

(2002) points out this is not as prevalent as the international labour mobility of worker is highly restricted, especially where developing countries are involved. Another channel that is mentioned in Radosevic (1999) is technology licensing, though its status as an actual channel rather than a mechanism of transfer is disputable. In Radosevic's review, licensing has been interpreted as being part of international trade, as it is essentially the selling and buying of technology. Others would argue that licensing is as part of a mechanism of FDI, that is MNEs license their technologies only to their affiliates, or in the case of vertical relation, only to their partners. Licensing and its effects are discussed in chapter 4, as they pertain to IPR policy.

The theoretical part of the review is centred around North-South general equilibrium models (Krugman (1979), Grossman and Helpman (1991)) as they provide the main theoretical framework to analyse these interactions. Usually those models have been declined in different variants that feature one specific transfer channel. While earlier models consider trade, newer ones look at the effects of FDI. There is a large empirical literature studying the different transfer channels, though not all are specifically looking at exchanges between developed and developing countries. The results are here too contrasted as we observe different outcomes, not only between channels of transfers but also within regarding specific channels themselves. For example, transfers through FDI are found to be significant both positively and negatively, depending on how the transfer occurs. Many different parameters are to account for, such as whether the transfer is done vertically or horizontally, the country and firms' learning capabilities may facilitate or prevent the transfer of knowledge or the strength of local ties a foreign firm has in a their host country. Regarding trade, different effects can reside in what type of good is being exchanged (capital and intermediary vs. consumer goods). Furthermore, while a few studies consider many types of interactions at once, most tend to focus on one type of transfer channel that results in a limited scope of study. As many parameters can affect the efficiency of technological transfers, technological development may spur in different ways according to the characteristics of countries and local firms.

This chapter serves to present the two main transfer channels, FDI and trade, in order to formulate our assumptions of how to model North-South interactions using an agent-based model. It is not intend as a comprehensive review, rather than a descriptive account of the mechanisms and their effects on developing countries. We first discuss international trade

as it is the most straightforward form of North-South interactions. We discuss how both imports and exports can be conducive to technological transfers. FDIs are then approached by differentiating vertical and horizontal spillovers. The mechanisms underlying FDI appear to be more diverse, which highlights the complexity of this particular type of interaction, and thus a potential interesting focus of study.

2 Transfers by trade

Exchanges of goods and services between countries is a way to gain direct exposure to new technologies, through the imports of new or better goods. In theory, greater trade openness should facilitate the acquisition of new technologies through this method. In the basic North-South model of (Grossman and Helpman, 1991), the technological progress of the South was facilitated by a greater trade openness which accelerated the speed of catching up (see also Keller (2001)). The more a country is open, the larger the potential for spillovers. This is of course provided countries are able to compete internationally, which is not necessarily a given for developing economies. In fact, we do see protectionist policies put in place by governments to protect against the entry of foreign goods, so as not to crush the local industries as they are still in their infancy. The protectionism vs. openness debate is not discussed here, though we do take into account the risk for a local industry which can be threatened by the entry of better or cheaper foreign goods. This mostly highlights the idea present in the literature that the efficiency of trade as a channel is not one-sided.

Box 1. Technological Capabilities: Enabling technological learning

We will see throughout the description of transfer channels as well as in empirical results that the success of each mechanism is subject to a sufficient level of *"technological capability"* or other terms that capture this idea that a set of factors is determinant in achieving technological progress. This notion is not new and can be traced back to the growth and convergence literature, starting with Gerschenkron (1962). The success of countries in catching up has been found to be dependent upon the development level of countries, as measured by a set of chosen characteristics. For Abramovitz (1986) it was called the *"social capability"*. As we saw in chapter 1 Verspagen (1991) uses the *"learning capability"* while Kim (1980) uses the term *"technological capability"*. The notion of *"national innovation systems"* (see Lundvall (2007) for a discussion on this notion) reflect a similar idea with emphasis on the dynamic nature and role of these characteristics. These terms refer to the role institutions, policy, development indicators (education, infrastructures), or cultural and social norms play in enabling the success of learning and assimilating new technologies. Cohen and Levinthal (1990) and Teece (2010) also discuss the role of such ability but at the firm level.

In their extensive discussion of this notion at the country level, Fagerberg and Srholec (2008) (and Fagerberg et al. (2015) for a more recent discussion) go through a large set of potential characteristics in an attempt to synthesise the concept through a factor analysis. They identify that the innovation system (made up of characteristics such as patenting, education and ICT infrastructures) and the governance (low corruption and enforcement of laws) were the most prominent factors that correlated with GDP.

Finally, Kim (1980) discusses the importance of the temporality regarding the effectiveness of each factor. Three steps of technological development are defined: implementation of the foreign technology (attracting the technology), assimilation (developing its usage) and improvements (perfecting and innovating on it). This means that each characteristic may play a different role in development at different times.

International trade provides new market opportunities and access to a larger diversity of goods. For Southern countries, both exports and imports can be conducive to technological development. We will see that the technological gains from exports do not necessarily stem from transfers per se, unlike imports which in theory should be a more direct vessel

for transfer through goods which embody the technology. Nevertheless, it would seem that firms with international scope have better prospects for growth. The gains of performance thanks to trade can be attributed to diverse factor: larger markets provide economies of scale and scope, while imports may offer more and better goods, thus creating price and quality competition on local markets. There is another advantage given by trade, that is its ability to provide opportunities for a country to acquire new technologies in a tangible form.

We start with looking at the effects of imports. A distinction in the literature is made with regards to imports of final goods vs. imports of capital and intermediary goods, as the mechanisms differ for each type.

2.1 Imports of final goods

Perhaps the most intuitive way to understand how trade contributes to technological transfers is to look at what would happen when a final good enters a local market. We note here that we refer to a final good as a good which is targeted to consumers (a.k.a a consumer good). We consider the case of a southern firm which imports a good from a developed country. This good contains in theory higher technology, which appear as new to the South.

Studies which look empirically at the case of imports of final goods on firms technological level are scarce ¹.

The choice for a foreign firm of exporting over producing in a developing economy depends on the conditions in the country. If producing in the local country is not appealing due to unfavourable production conditions such as an unqualified labour force or policies preventing the entry of foreigners, a northern firm can choose to export its product provided there are favourable policies in place such as low import tariffs (or at least no prohibitive ones). Given those conditions facilitating imports, the foreign good enters the local market.

Once the good is imported in the developing country, it becomes observable by local firms. The competition in the corresponding industry generally increases because of this better good².

¹The relative lack of empirical results is to be expected, because if a firm is to import a final good to resell it locally, it is not a firm which will have any incline towards producing this good later. However, imports of final goods can be to some extent conducive to technological transfers overall, and this is seen more theoretically.

²We imply here that good differs in terms of quality though we may also consider the case of final

Demand thus shifts towards the imported good. Local firms can respond in two ways (provided they have not been quickly driven out of the market). They can either start producing the same good (imitation) or try to innovate and produce an even better good. As is the case in North-South model framework, it seems that the theoretical approach favours the assumption that the South in presence of imports is an imitator, and have no ability to innovate, thus relying on innovations by the North (Grossman and Helpman, 1991). In this simple approach, allowing for imports of final goods into the South has for consequence to accelerate the increase of the local knowledge base, which allows for the South to reduce the technological gap faster. Models by Sala-i Martin and Barro (1995) and Currie et al. (1999) include the gradual ability of the South to become innovators, by presenting a trade-off for local firms between the innovation and imitation costs. In those models, at first the South does not dispose of enough resources to innovate, and imitation is more appealing to increase their knowledge base. The imitation costs rise as the variety of goods left to imitate decrease, that is there are less discoverable goods, and the remaining ones are technically too difficult to imitate so the South turns to innovation.

As we are dealing with developing economies, it is less likely that local firms have a strong ability to innovate (at least at first). It is however certainly not impossible either. Though basic theoretical models exclude this possibility, this assumption will have to be relaxed as emerging economies such as India and China show signs of increased innovations with an acceleration of patenting rates in recent years (Godinho and Ferreira (2012)). Srinivas and Sutz (2008) also mentions the phenomenon of "scarcity induced innovations" going with the idea that imported goods require some adaptive innovation to respond to local specific needs. Another motive for innovation by the South is the potential presence of IPRs which would force local firms who wish to compete against the patented good to innovate around the limits of the patent.

The imported final goods can provide technological transfers because local firms are provided with an embodiment of the technology from which they can learn, thus increasing the local knowledge stock. They can learn from the good techniques or designs by simple observation which they should be able to use in the future to help with further innovation. This is of course provided the firms do not experience too much of a deficit in knowledge

imported goods which present a price advantage over a quality one. This would mean that the foreign firm has found a more efficient way of producing the good. The technological innovation contained in the good is thus process-based, which makes it more difficult to be observed.

preventing them from innovating. It is a rather strong assumption, because usually if firms have the ability to innovate over the foreign competition then the need to import is less present. Connolly (2003) shows that high technology imports in fact usually dominate local innovation in developing countries when it comes to contribution to economic growth. She also confirms that imports help those countries with their innovation rates. This thus expresses the idea that imports benefit less technologically advanced countries, because the more behind they are, the more they stand to benefit from the innovation of others. Basically, developing economies will benefit more from the backlog of technologies available worldwide, which will then help them consolidate their knowledge stock, thus permitting future innovation. Countries with high innovation capabilities are less likely to benefit from the innovations of others. Therefore, imports of consumer goods containing advanced technologies benefit the innovation of local firms provided they have a minimum of technological ability, though not too much of it, otherwise the contribution would become insignificant. This is reminiscent of the result from chapter 1, suggesting a U-shape relationship between development and the reliance on imitation.

How the technology enters the local stock of knowledge is quite intuitive. As mentioned by Radosevic (1999) imports constitute an embodied form of technological transfers, and whether they decide to imitate or invent around it, the process relies on reverse engineering. This consists in taking apart the good and analysing how it was made and how it works to be able to replicate it. This is crucial to understanding that even in the case of simple imitation, some firm absorptive capability is needed. More specifically, the firm needs to have workers who are skilled enough to understand the technology and be able to replicate it. Simply put, having an electronic circuit in one's hands does not mean that anyone can just replicate it, they would need training in electronic engineering to be able to make sense of the technology. And even if they are able to understand the good, they would need to be able to physically replicate it. It could be that producing a particular good requires a particular piece of equipment, or the use of specialized inputs. This makes imitation not such a straightforward process. It is only once the good is technically understood and the firms are able to imitate it, that we can consider that the import has succeeded in transferring technology (see also Kim (1980)).

2.2 Imports of capital and intermediary goods

We now turn our focus to imports of capital and intermediary goods. They refer to goods which are used in the production process. It can consist in equipment goods or inputs. Just like in the previous case, imports of capital and intermediary goods embody the technology (Radosevic (1999)), as such the technology is transferred upon the purchase of the good. The technological transfer emanating from these imports differ from that of final goods. Where final goods relied on imitation through reverse engineering to permit transfers of knowledge, here the transfer of knowledge is more implicit. De Long and Summers (1993) find that there is a strong link between equipment investment and economic growth, thus suggesting that the imports of better capital goods may increase the productivity.

The intermediary or capital good is incorporated into the production process. Blalock and Veloso (2007) explains how the import of an intermediary good may lead to an increase in technology. Incorporating an input of higher quality in the production chain can lead to the production of a better final good. It can also optimize the production process through new techniques linked to this new element which results in better goods, or goods more efficiently produced. The technological improvement here is thus felt through on the production side rather than on the product itself.

It is an important form of trade, Radosevic (1999) mentions that in the 1980s, volume import of capital good was seven times the volume of FDI in developing countries, though now this number is declining. Coe and Helpman (1995) explain that the imports of intermediate goods means that when a firm chooses to use intermediate goods from around the world, it has access to a much larger and developed R&D stock. They then find positive evidence of productivity growth for OECD countries linked to imports.

In comparison with final goods, capital and intermediary goods are considered in the literature as more conducive to knowledge transfers. Xu and Wang (1999) find in their study on OECD countries that capital goods trade is a better vehicle than non capital goods to transfer knowledge, as they are carrying more R&D, therefore more able to increase the knowledge stock of a country. They do find however that it is not as efficient as other channels of knowledge transfer, such as FDI and licensing.

In order to be able to observe technological gains Coe and Helpman (1995) and

Schiff and Wang (2006), explain that the imports should be coming from more developed countries, implying that the import of the capital goods is beneficial mostly when there exists a gap in technology and that a minimum of technological ability to facilitate the absorption is necessary. Eaton and Kortum (2001) confirm this observation by stating that only a handful of developed countries (R&D intensive countries) export the majority of equipment goods. Furthermore they note that this trade is also subject to some bias (cultural and geographical) in terms of who developing countries chooses to import from.

Empirically, imports of capital goods are measured as imports in machinery and equipment (Coe and Helpman (1995), Saggi (2002)) and may sometimes include transportation. Coe and Helpman (1995) on a study on 77 developing countries find that countries are more likely to observe TFP growth if they are more open to capital goods imports (other factors also come into play, such as R&D expenditures and education level). They describe two ways capital goods imports can lead to productivity gains: the capital good embodies the technology (direct exposure), and makes available information. Overall, the evidence is rather positive. Xu and Chiang (2005) find that imported capital goods benefit mainly middle income and rich countries, thus underlying the role of development in gaining technological transfers from trade. This would suggest that low income countries do not have the sufficient ability to use foreign technologies. Amiti and Konings (2007) show for Indonesian firms that the lowering of input imports tariffs lead to an increase in productivity, thus confirming the link between import of capital and intermediary goods and technological transfers.

Damijan et al. (2003a) find positive evidence of trade (both imports and export) on local firms' productivity where they failed to benefit from FDIs. This suggests that these imports are suitable substitutes to FDIs, but not sufficiently so, as they find that FDI remains more efficient.

Katrak (1990) makes an interesting point regarding the contribution of imports to the technological level of firms. In his study on Indian firms, he distinguishes imports made to directly improve the production process, which show results quite fast against imports made to first enhance the technological capability of the firm, which are more long-sighted types of imports, in the sense that the results on productivity will take longer to show. He finds that at the time, imports made by Indian firms tended to be the more short-sighted ones. This is interesting to us because just like Merlevede et al. (2014) makes us consider

the time distinction for evaluating FDIs, the same can be done for imports of capital or intermediary goods. Katrak argues that socially, the short-sighted type of import is less desirable than the alternative which would require more adaptation and learning efforts. In his analysis Katrak adds that Indian firms which obtain an exclusive right, through the use of patents or licenses, of sales tend to invest less in R%D and make less import efforts towards improving the firm's technological capability. This could suggest a moral hazard resulting of patent protection. It is a direct illustration of the case of a monopolist which do no seek much innovative efforts once it obtains a right to exploit an existing technology, meanwhile local competitors will be given more incentives to make such technological efforts, provided they have the technological and financial ability to do so.

2.3 Exports

The literature on technological transfers considers that both exports and imports can be a channel of transfer. Clerides et al. (1998) and Jabbour and Mucchielli (2007) find that export-oriented firms perform better in terms of productivity than firms aiming for the local market only. This superior performance brings forward the question of whether exports can be source of technological progress for firms. The theory as well as the empirical studies relating to export and technological transfer remain nevertheless quite scarce. The learning by export mechanism is presented in the literature as such: firms entering the international market are confronted by consumers with higher quality demands and fiercer price competition. On the other hand, surely only the best local firms in an industry will tend to go to the international market. The question thus arises as to whether the high performances of exporting firms comes from an actual learning from the international market or from a self-selection. Jabbour and Mucchielli (2007) find that these firms can create spillovers to domestic industries similarly to what was observed with vertical spillovers from FDI, that is exporting firms would tend to employ upstream domestic industries, thus making them benefit from their international opportunities, however in their study those export oriented firms could be MNEs, thus questioning whether the effect comes from the exports or the if the exports enhance the benefits from FDI. Their study concerns Spanish firms, thus this concerns developed economies. For developing countries the learning process by export is more disputed. Clerides et al (1998) on their study on Morroccan, Mexican and Columbian firms find that the self selection argument is more

prevalent to explaining increased performance, and that there was little evidence of learning from export as they mention that very few changes were observed in terms of cost structures (thus production structure) after export. Similar evidence is found by Alvarez and Lopez (2005) in a study on Chile. This view is contradicted by Blalock and Gertler (2004) who do find evidence of productivity change on Indonesian firms after having exported. They find out, when interrogating some firms, the learning did come from buyers who would inform them of technical specifications; one example stated that the buyer recommended a particular equipment for the production of the good they sought. They mention that similar results were found in a study on sub-Saharan countries by Van Biesebroeck (2005) who also finds evidence of productivity gains after export. Their conclusion regarding these positive results is that their sample of countries (Indonesia and sub-Saharan countries) were on the lower end of the development spectrum in comparison to other studies which deal with countries such as Spain, Korea or Taiwan, meaning that these countries with positive results for export based learning had such a large technological gap that they were much more likely to experience gains in productivity. This tells us that the ability of exports to transfer technology is quite limited because (1) Self-selection plays a large part in the increased performance (only countries and firms able to compete do so) and (2) significant technological transfers may only be observed when in presence of a large technological gap.

Therefore, while exports can be associated with gains in productivity, the evidence remains quite scarce, and the effects are not as evident. It appears that transfers through imports are dependent on less ambiguous mechanisms, notably through the exchange of tangible assets.

3 Technological transfers through FDI

The second type of interaction we will be looking at are foreign direct investments. Foreign direct investments (FDI) consist in firms investing in other countries. This type of investment can take many forms: the firm could open up an affiliate in the given country, or enter in a joint venture with a local firm. The point is that the investment conducted abroad allows for the firm (here it will be mostly northern firm) to develop a presence in the South. On the production side, developing countries usually offer attractive cost

conditions with lower labour costs, and sometimes government offer incentives in the form of tax subsidies/fiscal advantages for example. It should be noted that it may often be the case where even if the production is outsourced, the target market is not the local one, and that production may be destined mostly for export purposes. Host countries might however still benefit from those FDIs. Foreign investments create local jobs, a demand for local industries (for example intermediary inputs), and potentially technological spillovers.

Those spillovers may be observed in two directions. They can spread within an industry, in which case we would be talking about horizontal spillovers, thus benefiting competing firms. Or, they can affect upstream (backward linkages) or downstream (forward linkages) industries, these would be vertical spillovers. Receiving FDI can thus represent an overall boost in the local economy. However, for countries to receive and benefit from those, they need to have the appropriate infrastructure and skills to attract foreign firms in the first place. Developed countries are more inclined to invest in developing countries with a good infrastructure; such as good roads or good telecommunications infrastructures. This is why a good proportion of the FDI are effectively made in developed countries. Regarding developing countries share, Asian ones receive the largest part, whereas least developed countries tend to be left out by northern investors.

Regarding the distribution trend of FDIs we can make the following observations. First, although we will tend to make the simplification that FDI means investment by the developed country, it should be noted that empirically it is not exclusively the case. The share of FDI made by developing countries is ever increasing³: In 1970 99% of FDI were made by developed economies, a number which slightly decreased in the next 3 decades, to finally sharply decrease in the beginning 21st century. In 2013, only 60% of FDIs are made by developed economies and 32% by developing ones. The rest is attributable to transition economies. The main explanation might reside in the classification of developing countries, which might not be appropriate for BRIC countries and other specific economies. The emergence of China as a stronger economy that invests overseas separates its case from other developing countries. On the other hand, the decline of the traditionally perceived as advanced economies countries is something to be noted in favour of those rapidly emerging countries and the role they play internationally. Regarding FDI recipients, in 2013, developing economies would be receiving 53% of FDIs vs 33% for developed

³UNCTAD data available at <http://unctadstat.unctad.org>

countries. Least developed countries only receive less than 2%. This shows that FDIs do not only represent a one-way North-South only type of interaction. Most importantly, this illustrates how development attracts investors. It supports the argument that LDCs lacking in capabilities cannot compete for investors, because they would be falling short of providing adequate production infrastructures and incentives.

This suggests that there is evidence of a preference for better skilled countries that are better equipped to receive higher technology. For example, Xu (2000) finds the existence of a threshold of human capital under which a country fails to attract FDIs. The variable for human capital chosen in this case is secondary education, and the author finds that under a certain average number of years of education, countries (least developed ones) tend to be left out. Xu cites previous studies that shows that FDI worked in Canada and Mexico (Globerman (1979) and Blomström and Persson (1983)), but not Morocco or Venezuela (Haddad and Harrison (1993); Aitken and Harrison (1999)). One of the explanation is that as the level of development was not high enough, the countries did not have the proper capabilities to receive efficiently and make use of foreign-supplied technology. Another aspect which may come in play is the cultural history: Javorcik et al. (2011) explain that migration networks can also influence FDI destination, suggesting that cultural affinities may also play a part in attracting FDIs .

Finally, it should be noted that FDI are not always welcome in developing countries. Notwithstanding the benefits mentioned above, developing countries governments have been known to enact policies to protect themselves against FDIs. This is because it could be perceived as if countries or local industries may not actually benefit from this. If a foreign MNE enters a developing country, despite the potential benefits, there is a high chance that the local industry would not be able to compete. Furthermore, if a firm is a direct competitor, it is highly unlikely that it will wish to share its technology. From that point on, FDI can represent a danger to the local economy, as all the financial and economic benefits will go back to the home country. As such, countries have been known to favour more participating type of implementation, for example joint ventures (Radosevic, 1999). In those instances, partly local ownership can insure to some extent that the benefits remain indeed local. This concurs with the opinion that developing governments which do not favour FDI may have tried to limit FDI investment out of concern that the technology will remain in the foreign MNE's hand and no benefit would be spread locally.

Nevertheless, the complexity of the effects of foreign firm presence on a local industry is explored next where we distinguish the different mechanisms linked to FDI. Mainly, two types of spillovers can be drawn: vertical spillovers and horizontal spillovers; or respectively, spillovers affecting the production chain (upstream or downstream) and those affecting the entry sector. This important distinction will help explain why contradictory effects may be found in the empirical literature.

3.1 Inter-sectoral transfers

Foreign firms might be able to transfer technology to a lesser developed country through their foreign investment by the exploitation of their backwards linkages with upstream local firms. A foreign firm entering a local industry creates those linkages by using local suppliers. We start by this mode of transfer because in theory foreign firms only stand to gain from sharing their technological needs with local supplying firms, since they are not direct competitors. Therefore we explore here the hypothesis that this mode of transfer is likely to be the most successful.

Javorcik (2004) mentions that in Latvian case, 82% of foreign affiliates use at least one local supplier, thus supporting the assumption that when a foreign firm enters a local industry, it creates those linkages.

Jabbour and Mucchielli (2007) study technological transfers on upstream and downstream local firms⁴, and find that in the case of Spain, the presence of foreign firms significantly improves the productivity of upstream firms. Blalock and Gertler (2003) find similar positive results in the case of Indonesian upstream industries benefitting from FDIs in the local downstream industries. They quantify this by estimating that increase of 20% of FDIs' share in the downstream industries causes a 2% productivity gain in the local supplying industry. Javorcik (2004) find similar evidence for Latvian industries, however her results are more contrasted in the sense that the form of the investment is important. Mainly, she shows that fully-owned foreign affiliates are less conducive to vertical transfers and that local participation (i.e. through joint ventures) in those FDIs is important, as local firms possess knowledge and links to the local upstream industry and are in a better capacity to exploit these backward linkages. The motives for the creation

⁴The evidence in the literature for the transfers through forward linkages is very limited, for this reason this channel is not discussed here

of those links include taking advantage of lower intermediary product costs and savings on transportation costs. Those cost-savings opportunities are also what could encourage a foreign multinational to choose this particular country as their investment destination.

Theoretical approaches by Rodriguez-Clare (1996), Markusen and Venables (1999) and Lin and Saggi (2004) also support the relevance of backwards linkages when it comes to transfers. Markusen and Venables (1999) find that FDIs can act as a catalyst for development precisely through this channel. Lin and Saggi (2004) provide a two-sector framework with an oligopolistic competition in the final goods sector, where the impact of FDI is represented horizontally - the local competition is negatively affected - and vertically where through the exploit of linkages, vertical technology transfers are successful.

Technological transfers can arise from those linkages as explained by Moran (2001) and Javorcik (2004), through the improvements brought forward by the foreign firms to their local suppliers. Under the hypothesis that the foreign firm produces a good which is of superior quality, or that it relies on a more advanced production method, their input requirements are of higher quality. Foreign firms will thus help their suppliers to either produce inputs of higher quality, encourage innovation, make use of higher quality raw materials or even contribute to improving their production process. This transfer process is also reported by Blalock and Gertler (2003), in the case of Indonesia where investing American and Japanese firms would send their engineers to their Indonesian suppliers in order to suggest improvements, and would then test the results before using them at a large scale. This set of evidence also reinforces the idea that a firm from the more developed North invests in a developing Southern industry, and ends up improving the upstream Southern industry's technological level.

As a result of this intervention by the foreign firm on the local supplier, the inputs are of higher quality and/or lower cost. The local supplier has thus received a direct technological transfer from their foreign customer. Furthermore, Javorcik (2004) mentions that as a result of this technological improvement on the upstream industry, the technological spillovers may trickle down to downstream domestic firms (i.e. the foreign firm's competitors). This is due to the fact that the upstream firm is now producing inputs of higher quality, which may be sold to the downstream firms, which will then enjoy a technological improvement in their production process, resulting in either more efficient production or goods of higher quality as they are made with higher quality inputs. This is conditioned upon the ability of

the supplying firm to use the knowledge obtained through the transfer with other competing firms.

When modelling this mechanism, the important aspect to account for is the fact that backward linkages induced transfers are completely voluntary, as they stem from the desire of the more technologically capable firm to train their suppliers and expend their expertise as well as their resources in order to improve the quality of the inputs provided as well as optimizing the costs. The indirect effect on the local industry should also be accounted for, that is the improvements in the South supplying industry causes technological improvements on the local downstream industries. As such this mechanisms, which was at first a form of purely voluntary transfer, may lead to vertical involuntary spillovers. Of course, the success of these transfer would depend on the absorptive capacity of the firm, as shown in Jabbour and Mucchielli (2007). They find that upstream local firms with a higher technological gap tend to benefit less from those transfers than firms more technologically capable, echoing a selection effect on local firms. We note in this case that they used the technological gap with the foreign downstream firm as an inverse proxy for the absorptive capacity of the firm. The logic behind this measure is that the farther away (technologically speaking) a firm is from the prospective buying firm, the less it would be able to apply the technology requirement set by the foreign firm. This is also seen in the Blalock and Gertler (2003) example, where they mention that a Japanese firm investing in Indonesia choose to keep their Japanese suppliers, citing the fact that Indonesian suppliers were not able to adapt their production to the expected quality (or price, or timings). If a developed country's firm wishes to successfully transfer knowledge, then the receiving firm must have the ability to process and use efficiently this knowledge. The absorptive capacity of the firm (Cohen and Levinthal, 1990) describes the ability of a firm to process this new knowledge; aspects like individual specialist training to the organisational ability of the firm are important. As such, representing the absorptive capability of the firm as the technological distance between the foreign firm is quite adequate, as here the successful transfer pertains precisely to how technologically compatible firms can be. A local supplier with a higher absorptive capacity, that is a smaller technological gap with the foreign firm, would be better equipped to receive the transfers offered to it.

We mentioned earlier that the evidence in the Latvian case provided by Javorcik (2004) was conditioned upon some form of involvement by the local industry in the FDI. This

condition for success is also later shown in the Romanian case by Javorcik and Spatareanu (2008). In the case of local participation, they argue that local firms are better equipped to exploit the local supply network and linkages, thus encouraging vertical spillovers. However, they argue themselves that while externalities due to FDIs are observed more significantly in the case of local participation, the actual source of the observed productivity gains can be from knowledge transfers as well as competition effects. The latter is different from the actual transfers that we wish to analyse. This local participation factor should thus be accounted for as it is a variable which serves to define the shape of the FDI and can influence the success of the transfer process. In terms of transfer of technology, the local partner gains direct access to the technology the foreign firm is willing to share, which as a result can be potentially assimilated by the local partner. This can be source to horizontal spillovers, but also vertical ones. Given the previously mentioned stronger ties with the local upstream industries, Javorcik and Spatareanu (2008) argue that foreign firms with local participation (i.e. joint ventures) are more likely to use local suppliers. This means that if a foreign firm decides to conduct some FDI in a developing country by using a form of partnership with a local firm instead of conducting some greenfield investment then the local upstream industry is more likely to be solicited, thus making the transfer channel by way of backwards linkages stronger. Additionally, local participation can have a more direct horizontal spillover effect as the local industry gets more direct exposure to a given technology, and local labour turnover could help transferring technological knowledge locally.

3.2 Intra-sectoral transfers

An important aspect to retain concerning vertical spillovers is that they tend to be voluntary, that is the foreign firm wishes to transfer their technology because it benefits them to do so. In the case of horizontal spillovers, however, the transfers are involuntary. Firms do not wish to disclose their technology to their competitors. This type of spillovers are where most ambiguous results lie regarding the efficiency of FDI to facilitate transfers of knowledge. We thus now look into the different mechanisms in play here.

3.2.1 Horizontal transfers studied in the literature

If knowledge from the foreign firm is diffused throughout a same industry, this means essentially that its competition has gotten hold of part of their technology. The fact that it concerns the competition is why we refer to those type of transfers as horizontal.

We take the case of a firm from a developed country which enters a developing country in a given industry. This firm has in general access to better technology. This could mean that it produces a higher quality good, or a new good, or that their production process is more efficient. The decision to enter an already existing industry may be motivated by factors such as access to a lower cost labour force, exploiting a local market, or taking advantage of pro-FDI policies.

Creation or acquisition of technology can be a costly process. The R&D costs and the risks associated with innovation makes knowledge an expensive advantage which firms should be seeking to protect. It should be stressed that obviously a foreign firm entering a local market with a technological advantage is not going to want to share its technology with its new competitors, and seek to protect it. Sharing the benefits of an innovation decreases net profits and further innovative incentives. Also more generally, if a firm has a competitive advantage, it is bound to seek to protect it rather than sharing it. The consequence of this situation is that if horizontal transfers of knowledge were to happen as a result of FDI, then they would not be intentional. We would qualify those horizontal spillovers as involuntary. Radosevic (1999) uses the terms active and passive regarding the role of the foreign firm, as such if transfers are involuntary, the role of the foreign firm is passive as they not are actively (or in most cases at all) trying to transfer technology. This will have an incidence on the results regarding the efficiency of this mechanisms and the effect of IPR policy. More precisely, if firms are not willing to transfer knowledge, then transfers are less likely to occur. Therefore, if significant evidence of transfers cannot be found, then part of the explanation may belong to the very nature of this channel.

For the case of intra-industry spillovers from FDI, part of the literature consider that positive horizontal spillovers occur if there is a gain in productivity for the local industry. The estimation of those spillovers however poses a measurement issue because often the average productivity of this local industry is used to measure spillovers. If the average productivity increases, multiple reasons may explain this. It could be that local firms

have to react to a stronger competition (Kokko, 1992) calls this competition effect), and thus increase their productivity on their own, without using the competitors' technology. Another aspect of this issue is that the foreign entrant may be so efficient as to drive the local firms out of the industry, thus increasing the average productivity in the country. This shows that productivity gains may result out of horizontal FDI without having an actual transfer of knowledge happen. The entry of a more advanced firm in local market can have negative effects on the local industry. For example, instead of transferring new technologies to other firms, local firms are outperformed, and driven out of the market.

The theory tells us that if there is an increased presence of foreign firms then more technology can be imitated. In basic North-South models which incorporate FDIs such as Glass and Saggi (1999) or Lai (1998), this is effectively the case. In those models low wage levels in the South are what attracts Northern firms. Once they reach the local market, their technology becomes open for imitation by Southern firms. If they manage to imitate the technology then the production of the good switches to those local firms, freeing up resources for innovation in the North. This is of course a simplification, but the main result to take from this is that the presence of foreign firms facilitates imitation and thus technological transfers. Another theoretical approach is Wang and Blomström (1992) who explain that the threat of imitation and intensified competition leads to foreign affiliates of MNEs to be more reactive in terms of innovation, as to render previous technologies outdated. The theory thus argues in favour of positive spillovers through FDI.

The main problem with those models is that they fail to acknowledge the negative impact for local firms in the industry by the entry of a competitor.

The empirical evidence is less straight forward. The answer to the question of whether FDI leads to more technological transfers in a industry is not one sided. Some papers find no evidence, other find positive evidence. Görg and Greenaway (2004) list in their appendix the different studies on different countries and their outcome regarding intra-industry spillovers. They only find that 19 of the 40 studies give significant results, which means that more than half fail to see evidence of technological transfers horizontally. There we can see that transition countries register mainly negative horizontal spillovers. Developed economies mainly register positive spillovers; this probably because they are able to respond to the competition by improving their own technology as well as the fact that their absorptive capacity is high enough that they can learn easily.

We can mention other studies such as Taymaz and Lenger (2004) which fail to find evidence of horizontal spillovers for FDI in the Turkish manufacturing industries in both low and high tech sectors. They attribute this to inefficiency of demonstration effects (reverse engineering) to transfer knowledge. Damijan et al. (2003a) on their study on Eastern European countries even find evidence of negative spillovers, suggesting that the competition effect can overtake potential benefits.

The firm's absorptive capacity certainly plays a role too. As Gorg and Greenaway point out, it is possible when looking at an industry where firms' capabilities are heterogenous to find that those different firms experience positive spillovers while other firms are lagging behind because they are the ones who fail to compete against the more developed firms in the industry.

Another argument put forward for the different results is the estimation method: cross sectional vs panel. The latter being a dynamic estimation allows to estimate effects over time. If we consider that the effects are not immediate, then we would not expect to see results right away, and the negative immediate effect of a foreign entrant should be dominant. Or if we face positive results, it is likely that much of it should be attributed to competition effects.

3.2.2 The transfer mechanisms behind the horizontal FDI spillovers

Nevertheless, transfers can and do occur through FDI. The mechanism behind transfers in this case is presented as demonstration effects (Kokko, 1992), that is the technology is somewhat exposed and is being reproduced either by reverse engineering, or through labour turnover (Teece et al., 1977).

The presence of the foreign technology makes it more vulnerable to being observed by the local industry, in which case they can attempt to reproduce it, if they can in the first place. Imitation takes skills. The local industry must have a trained workforce with the ability to analyse and recreate what they observe. Another limitation is the technological resources available to the local industry. Maybe the workers are able to imitate the product, but without the right technological equipment or infrastructure, imitation is not possible.

The other mentioned mechanism which permits horizontal transfers is that of local labour turnover. When a foreign firm enters the developing country, it can choose to hire a local workforce. Those local workers, provided they are sufficiently skilled, are then

trained through a form of "learning by doing" by the foreign firm. They are thus directly transferred the knowledge by the company and have acquired a set of very specific skills. Blalock and Gertler (2003) mention that at first this creates a negative effect of the presence of a foreign firm in the industry: it causes a brain drain on the local industry. That is the more qualified workers will be hired by foreign firms able to offer higher wages and better skill development. Now, if a worker decides to leave the foreign firm to work for a local firm, then she brings with her this specific technological know how and is able to help the local firm develop to the level of the foreign firm, by communicating this technology, as well as know-how and knowledge of the practices of the foreign firm. The success of this type of mechanism is of course dependent on the level of education of the workforce, so that the foreign firm chooses to hire them but also so that the workers can be further trained. Similarly to the simple imitation effects mentioned above, the local firm also needs to be able to receive this new technology, which means they need to have sufficient financial and technological resources.

Merlevede et al. (2014) also add a time dimension to the question. If some papers find no evidence of technological transfers or positive spillovers, it might be because not enough time has gone by since the introduction of FDI. They find that horizontal spillovers are significant, though in a longer term as the positive effects remain sustainable in the industry. The explanation behind this is that imitation and labour turnover take time. This is even more true for the latter. Years have to go by before a local worker switches back to a local firm, and even then this should be conditioned upon local firms being attractive enough for this newly trained worker (higher wages, not too technologically behind.) This is also observed by Liu (2008), who explains that though the local productivity level within the industry decreases at first following the entry of foreign firms, in the longer term they end up increasing. The time-lag is interpreted here as the time needed to build new production capabilities in the face of increased competition. What drives the subsequent productivity growth is the growth in human capital and technological level resulting from the training offered by the foreign firm. The labour turnover effect has been studied theoretically by Fosfuri et al. (2001) who model precisely this mechanism where the foreign firm trains the local worker, and is usually able to retain them through higher wages. Technological spillovers may occur when those workers switch to local firms. In their model, this happens when there is symmetry of information between southern and northern firms, as southern

firms are able to identify the potential gains of hiring those particular workers, in which case they raise their wages to incentivise those workers to switch firms. The threat of these technological spillovers can dissuade foreign firms from engaging in FDI. This is a potential effect to keep in mind as it relates to the main question of this thesis. In a similar spirit, Görg and Strobl (2005) find positive evidence in a study on Ghana that managers trained in MNEs end up being more productive than domestic firms when they start their own firms. Further evidence is found in Hale et al. (2006) in a study on China, though the transfer of knowledge was done through highly qualified workers in local advanced firms only.

4 Conclusion

This chapter offered an overview of the different mechanisms in play that may be of interest for modelling the catching up dynamics of developing countries through technological transfers. The mechanisms identified range from simple reverse engineering, spillovers from inputs, training of suppliers and labour turnover.

From a policy perspective, governments wishing to facilitate technological transfers have to consider two types of policies that are complementary. First, national policies to encourage the development of technological capabilities, such as education, infrastructure or improving governance and ease of doing business, are necessary to lay out foundations to enable technological learning by firms and the population. For without the necessary capabilities, it has been showed empirically that trade and FDIs would not lead to significant technological spillovers. The second set of policies thus concerns the openness of the country, such as lowering trade barriers and pro-FDI policies in order to allow the transfers to happen once the countries have reached the capabilities to assimilate them.

For our modelling purposes, the set of mechanisms rich by their diversity and complexity, provides us with interesting perspectives for representing the interactions between North and South. Ultimately, to gain a comprehensive understanding of the efficiency of each channel, one would need to study them all at once in a complete model. This would require modelling not only the developing economy, but also multiple sectors and an outside market, with all the economic mechanics those entails. This would prove to be quite a large and complex endeavour, for this reason the model in the following chapter

will be focusing on modelling one transfer channel in one sector, with the perspective of further improvements.

Particularly, the last mechanism studied here, labour turnover in a developing country, seems to be an area of interest as few studies have been done empirically (and theoretically) on the subject, and the underlying dynamics involved in this particular channel, such as the labour market and the development and transfer of skills could be quite engaging from a modelling perspective.

Chapter **3**

North-South catching-up: an analytical approach using an Agent-Based Model

1 Introduction

Technological progress and economic catching up are complex processes. As we saw in the previous chapters, the dynamics that lead technological progress, imitation and innovation are the result of the interactions of firms and countries with technological leaders.

We found that technological transfers do not necessarily happen when northern firms enter a southern market or industry, whether by trade or FDI. Essentially, the previous chapter showed that multiple mechanisms were in play and developing countries and their firms own characteristics could affect the success of technological transfers. Therefore it is of interest to try and understand what makes the channels more or less efficient in transferring knowledge.

Given the complexity of all the mechanisms involved and the interactions between agents, we choose to represent this through an agent-based model (ABM). Computational economics allows for the modelling and studying of complex systems, which would not be possible otherwise.

The North-South ABM here built is a macroeconomic model that attempts to represent the North-South interactions. These situations have not yet been explored by ABMs. It is in the same spirit as comprehensive models such as the Eurace model Dawid et al. (2014), in that it attempts to model a whole economy so as to be used for policy analysis.

The number of mechanisms described in the second chapter, as well as the plurality of channels, makes it complicated to model all those interactions at once. Therefore we here choose to focus on one channel, which is the FDI horizontal spillover channel. It is the simplest channel to study as it requires no external market (unlike international trade), and is focused on one sector only (unlike vertical spillovers). It therefore offers a good starting point for this model. Other channels can be explored later as part of future research.

Underlying horizontal spillovers are two transfer mechanisms, imitation and labour turnover (Merlevede et al. (2014), Fosfuri et al. (2001)). The transfers through local labour mobility work as follows: a worker who has worked for a firm and learned their technology through training and then gets hired by another firm may transfer the competencies acquired in the previous firm. Therefore the firms through this mechanism learn new technologies thanks to their workers. The rich set of dynamics behind this mechanism make it a particularly interesting focus of study. Focusing on this particular channel means that the model has to include components like a labour market and a system of skill development on the workers' side. Thus, the model does not simply focus on firm performance but also considers workers' welfare and development. This is particularly interesting as it allows us to get a more comprehensive look at the effects of technological transfers.

A few ABMs have focused on the labour market including the model on the French labour market Ballot et al. (2013) and the extension of the Eurace (see Dawid et al. (2013)). The latter one also features a skill system where workers from different regions have different skill levels and their mobility affect the productivity of each region, though firms do not learn new technologies. To my knowledge, labour mobility as channel of transfer has not been studied in ABMs.

The chapter is organised as follows: we start by an extensive and comprehensive description of the model and the different blocks that compose it. We describe the technology space, the skill system in place, the labour market, the goods market, the tax system and the how R&D works. We then run the model and analyse the results to see what the model as it is built tells us about the effect of the FDI channel of transfer through the labour turnover mechanisms. Mainly we focus the analysis on answering three questions: do southern firms benefit from FDIs? to what extent? We also investigate the conditions under which northern firms perform better, so as to be able to understand the potential conflicts between both types of firms' interest.

2 The North-South Agent-Based Model

2.1 A general overview of the model

The model represents an emerging country, also referred to as the South. In this country there is a single industry that employs the local population. The industry, made up of southern firms, produces a homogenous and perishable good destined solely to the local market. This sector has been closed to international trade, therefore no export or import of that good are possible. However, the government in the hopes of generating technological transfers, has decided to open up the industry to foreign firms from more advanced countries (the North) wishing to invest in the country, and set up local affiliates. As a result multinational enterprises (MNEs) from advanced countries have engaged in foreign direct investment in the industry and entered the market through greenfield investments. The industry is thus now made up of a proportion of southern and northern firms. The northern firms are thus supposedly more technologically advanced, which here means they are more efficient producers. Here we assume that after the number of firm has been determined (after the FDI), no further entry of firms, whether local or foreign, may happen. Households are also shareholders of firms in the industry (both northern and southern), which means they earn dividends on the profits.

The population is made up of households of workers. The population grows, and future workers receive some education before entering the job market. A limited few workers decide to retire after having worked in the industry for a long time. The northern firms must use the local workers only as there is no international labour mobility possible.

Although workers are educated, once they find employment at one of the firms (either northern or southern), the firm trains them to work under their processes so that they become efficient employees. The labour laws in place determine the length a firm must contract employees. As a result workers who find jobs have a certain level of job security until their contract end (and the firm chooses not to rehire them), or the firm can no longer afford them, they become unemployed in which case they must search for another job (while receiving unemployment benefits).

Within the firms, employees produce the goods. Skilled employees are more efficient but they also have the ability to share their skills and experience acquired while working

for other firms. This sharing may help the firm improve their process. In the basic version of the model, firms first attempt to observe their competitors and imitate their processes through the help of a worker with the corresponding skills. They also search for their own improvement (innovation) by investing in R&D. Here again, the employees past experiences may be beneficial in the research process and may help the firm significantly improve. Through this research process and the help of informed workers, southern firms may eventually learn and assimilate the production processes of their northern counterparts, in which case the technological level of the South will have matched that of the North, thus succeeding in catching up.

Firms thus produce goods, sell them to the local market where the households buy them using their income from wages and dividends, earn (maybe) a profit that is reinvested in R&D or used for expansion through capital investment ¹.

Regarding the technological transfers, given that we only represent one sector, only horizontal transfers are possible. Furthermore, foreign technology is only present through the northern firms that have settled in the country (FDI source) and given that we are dealing with process innovation, the technological transfers will be coming from sources inherent to the production process. As such, in this version of the model, we assume that technological transfers may only come about through the labour force, as they are in direct contact with the technology and its usage.

2.2 Sequence of operations

The model presented here has the potential to offer a rich framework for development policy analysis without making consequential changes. Such changes may however be added to expand this already complex model. This the case of chapter 4 which will focus on presenting a patent extension to the model.

In addition, a quite large diversity of policy choices may be tested. For example, regarding FDIs, changing the number of northern firms and their initial advantage we can test the impact of protectionist policies vs pro-FDI ones. The education parameter, after some precisions, allows to look at whether improving education can have a significant impact on the industry and economic growth. Taxation policy (FDI incentives, local subventions) as presented in its basic form in section 2.10 may also be experimented with.

¹The capital sector is external, does not evolve technologically and is not represented here

Development related questions can be studied through this model. Besides policy choices, the economic state of the country itself (over which the State does not have direct control) can yield different outcomes. The different levels of development here can be tempered with by modifying the technological gap variable. The educational gap can be interpreted as the inner inequalities. The basic wage level (see section 2.6.2) can be looked to see if foreign and/or local firms can thrive in low labour cost setting, or if higher wages are necessary to elevate demand opportunities.

Before we delve into the intricacies of this model, we present here a quick overview of the steps that happen at each repeated period.

1. Firms start by adjusting their labour force according to their needs and/or capacity, given their capital stock. As workers (both unemployed and employed) search for jobs, firms decide if and how many new workers they will recruit or let go.
2. Firms start or continue to train their workers so they can learn how to work on the technology used by their employer. As workers gain experience (or lose some), their skill level evolves, and this will be reflected in their productivity while working for their current employer.
3. Firms produce their goods, determine their own prices depending on their costs, pay their workers' wage and proceed to sell the production on the local market.
4. Workers buy the goods depending on their income. Firms compute their profits (or losses if they did not manage to sell everything) from their income from sales. They pay taxes and dividends.
5. With the equity left, firms engage in R&D by trying to innovate and/or imitate. If they are successful, they change their production process when adopting a new technology.
6. Firms decide if and how much they will invest in capital. Investment in capital represents the expansion of the firm. Such expansion will be accounted for at the beginning of the following period when the firm looks to hire new workers to adjust their labour force to match their investment.

The following sections are organised to explain the different aspects of this model. To model this complete sequence, after presenting the agents (firms and workers), we

need to define a technological space to understand how technology evolves in this model. An important development of this model is the gradual approach to radical changes in technologies, necessary to represent a process of technological transition of the South towards the North. We also had to devise a workers' skill system in order to be able to have technological transfers through the labour force. An interesting aspect of using this system is that the productivity of worker is now dependent on their experience, implying that the firms do not necessarily make the most of their technological discoveries. The functioning of the labour market is presented next, followed by the production process and how supply and demand interact on this market. Finally we look at the R&D of firms. While we take a common imitation and innovation approach to this process, a few novelties are used here, notably the use of score functions to compute successful outcomes probabilities. Once this model is fully described, we ran simulations to present the main dynamics manifesting here.

2.3 Agents and their basic interactions

2.3.1 Differences between southern and northern firms

Those foreign entrants in the industry may have entered with advantages over the local firms. Those advantages can take the form of capital advantage, where the firm starts out with a larger amount of capital than local firms. In theory this means that those northern firms start with higher production capacities. Additionally, they may also start with a larger amount of equity, thus alluding to deeper pockets than local firms. This could allow them to get a head start in recruiting better workers and/or provide greater investment funds. The most important advantage they have, however, for the purpose of this model is the technological advantage. Instead, technological advancement will improve the production process (process innovation), meaning that the more technologically advanced firms should be the more productive firms. We will see that having better productivity allows for the firm to keep their production costs down, and thus enables to offer more attractive prices to capture a higher share of the demand. As section 2.8.1 explains, obtaining higher demand can be crucial to making profits and ensuring firm survival.

The size of the advantages of the North are parameters to be specified in the model. We can set the starting capital and equity for each type of firm, noting though that all firms

from the South are created equal and all firms from the North as well. The technological advantage of the northern firms is seen through the technological gap between North and South. We consider that the foreign firms are situated on the technological frontier (see section 3.1) whereas southern firms are using lower technologies. The gap between those technologies constitutes the technological gap.

Firms and firms-specific variables in the model are identified by the subscript i . The number of both northern ($nbnorth$) and southern firms ($nbsouth$) is determined at the start. The total number of firms (nb_firms) is fixed at twenty for these runs, we only modify the ratio of northern to southern firms. This allows us to study the impact of the scale of foreign entrance on the industry, and more specifically on local firms. We expect, for example, that an overly large proportion of northern firms will force the local firms out of the market. On the other hand, if the number of foreign entrants is too limited, the local firm should be less likely to benefit from technological transfers from FDI. There is no entry or exit of firms here. They may stop producing and stop their other economic endeavours (investments, R&D) due to poor performances leading to seemingly unrecoverable losses. It is possible however that as market conditions improve and become more favourable for similar firms, arrested firms may be tempted to return to the market and resume their development from where they left off.

2.3.2 The workers

The workers make up households that earn wages and dividends through the shareholdings of firms. If they are unemployed they receive unemployment benefits as they search for a job. The industry solely serves the local market. The market is made of workers who look to work in the industry in question. Other industries are not modelled here, effectively meaning that if a worker fails to find employment at any firm, they are unemployed. Workers are also shareholders of firms, thus earning dividend on firms' profits. This means that there are potentially three sources of income for households to make up the demand: wages paid by the firms, dividends and unemployment benefits. We start the model with a number of workers ($nworkers$) chosen exogenously. Workers and their variables are identified with the subscript h . This number will be fixed at 100 workers at the start of the period. New workers enter each period, while the oldest workers have a increased probability of retiring as their age increase. The net growth of the population remains positive though,

thus the population increases over time. Workers start with no experience except some level of basic education. The national average level of education (edu_{NAT}) is fixed and is supposed to reflect the investment a state has made in educating the population. Workers are not equally educated. In the developing countries some workers attain a higher level of education than others. We define an educational gap variable edu_{GAP} . This reflects the inequalities present in the country. To keep things simple, workers' education edu_h can take two values:

$$edu_h = \begin{cases} edu_{NAT} + edu_{GAP} & \text{for the highly educated workers} \\ edu_{NAT} - edu_{GAP} & \text{if the worker received low levels of education} \end{cases}$$

The level of education will determine mainly the speed at which new technologies are learned and the initial skill of the workers. It does not play a direct part in determining the productivity of a worker. We do expect it to give a head start to better educated workers. For now we assume that the distribution of quality of education among workers is equally split between high and low educated workers. Finally, although the education variables do not change throughout time, the level of starting skill does (see section 2.5.3) to reflect the idea that the content of the teaching evolves but not the quality. New workers therefore may start with higher skills than their elders but the discrepancy in education quality remains.

2.4 Technology space

The technology space in this model is made up of technological trajectories, akin to technological paradigms (Dosi, 1982). Those different technological trajectories (indexed as p) represent technologies which significantly differ from one another. There is a continuum of versions θ of the technology which form each technological trajectory. As the value of θ increases, the technology improves reflecting a move ahead on the trajectory. An improvement in a technology is reflected through an increased the productivity of the firm A . θ identifies a technology on given trajectory, therefore we define each technology j by the vector (θ_j, p_j) . That is, each technology is defined by the trajectory and its location (or version) on it. A change in trajectory represents a radical innovation in technology whereas a change in θ represents an incremental innovation in technology. An incremental innovation is a small change in the technology used by the firm, which can be interpreted as an improvement on a current technology. A radical innovation implies a more substantial change in technology, usually requiring greater adaptation of the firm to this technology through new equipment, retraining of workers and/or and some organisational change.

2.4.1 Structure of technological trajectories

The technology along a trajectory evolves in steps. At the beginning of the trajectory steps do not provide much productivity gain as the technology remains basic. After a few discoveries, the gains start to increase. Towards the end of the trajectory, there are few improvements to be made, so steps provide less and less technological gains.

The evolution of productivity follows a logistic-shaped function pictured in figure 1. For a given technology j with (θ_j, p_j) , its productivity A_{θ}^p associated on the trajectory p may thus be calculated through the following equation:

$$A_{\theta}^p = A_{min}^p + \frac{A_{max}^p}{1 + e^{a_1 * (\theta_j - a_2)}} \quad (3.1)$$

The logistic function describing productivities is defined by the parameters A_{min}^p , A_{max}^p , a_1 , a_2 .

A_{min}^p is the minimum productivity on a given trajectory and A_{max}^p the maximum productivity on this trajectory. Both are asymptotic values due to the nature of the logistic function. The asymptotic maximum suggests that at some point, the technology may not

be improved upon to register significant gains in productivity, and thus firms desiring to improve their production methods should look to better technological paradigms, if they exist.

In order to keep a coherent and simple technological structure in the model we assume that trajectories do not cross, that is different technological paradigms may be ranked. This is reflected through the a_1 and a_2 parameters which are the same for all paths. a_1 is the slope of the logistic curve, representing the speed in increase of productivity from incremental improvements. A higher slope means that technologies in this field will take a long time before they can lead to significant improvement, though this improvement will be major until improvements enter the asymptotic phase. A smaller slope on the other hand corresponds to the a field where incremental innovations leads to a more gradual increase in productivity. a_2 is a "centering" parameter, which corresponds to how fast the upper asymptotic phase is reached. Furthermore, the distance between A_{min}^p and A_{max}^p of different trajectories is constant, meaning different trajectories are always perfectly parallel. The distance between trajectories may be interpreted as a factor which makes radical changes more or less difficult.

As represented in figure 3.1, we start with only two trajectories at first. One path represents the technological paradigm used by the North and the path below is the path followed by the South. The distance between trajectories represents how far apart the two countries are technology-wise. A larger gap between the two paths means that the developing country is particularly behind and as such the disadvantage it will suffer from is larger. A smaller gap means that the Southern firms' chances to handle the competition from the Northern firms and eventually catch up to them are much more likely.

In essence, the technological trajectory followed by the North may be considered as the technological frontier in the model. The gap with the South technology represents how far behind the South is.

2.4.2 Modeling transitional technological change

A local firm may be considered as caught up when it is using a similar technology to that of its more advanced competitors. Therefore reaching the technology considered as the technological frontier is a necessary step in the catching-up process. An important aspect of this process is how the frontier is reached. Here we assume two ways are

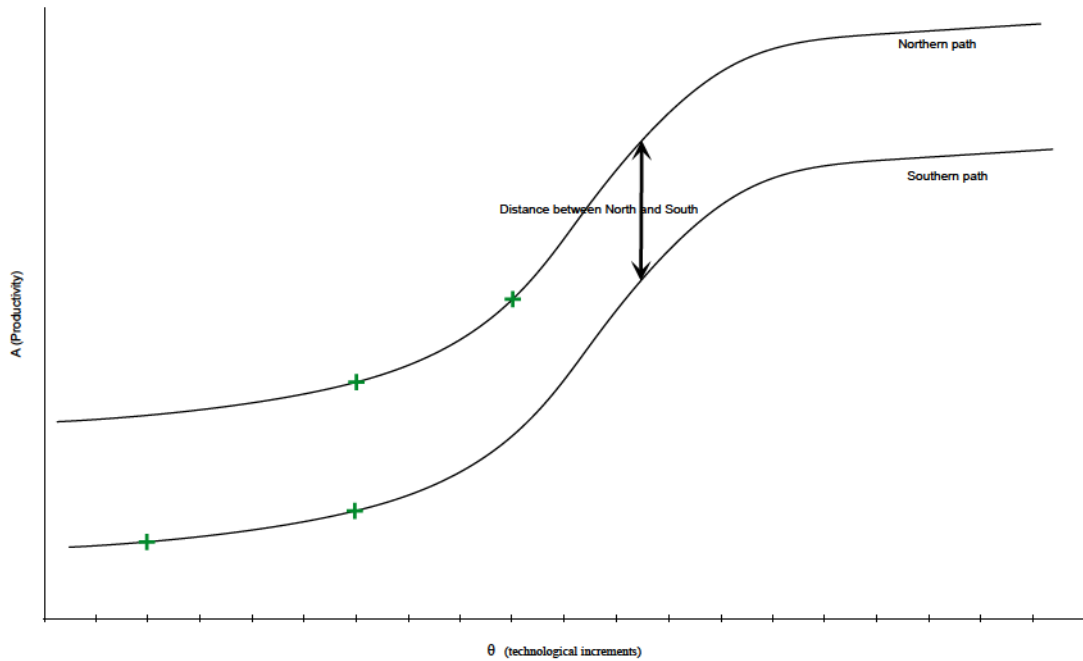


Figure 3.1: *Technological space with two trajectories*

possible. The traditional approach, that is the southern firm somehow acquires an existing northern technology (through imitation for example) and is directly moved to the northern trajectory. The second way supposes that the southern firm reaches the frontier on its own. In innovation economics models, when radical innovations happen they involve a discovery of a new trajectory and usually the firm discovering the new trajectory starts at the beginning of this trajectory. Here a different approach is taken to fit better the context of catching up. The southern firms are still capable of making those radical discoveries, however we have to account for the fact that the northern technology is already on an existing higher trajectory and has probably made its own progression. The issue we wish to address here is whether the southern firm making radical innovations should be starting from scratch on new this new paradigm. Srinivas and Sutz (2008) discuss the innovation context in developing countries and explain that technological development in the South exists under the concept of "scarcity induced innovation". The idea is that innovation in developing countries responds to local particular needs (innovation follows "idiosyncratic paths") and is limited by local capabilities. In short this means that for the South radical change is quite an unlikely scenario. Rather, the process is gradual. Furthermore, as technology advances in the North, a large part of the innovation process of the South consists in the application of technologies developed by the North to respond to their own problems. Thus

when innovation happens in the South, it may take the form of incremental innovation (simple improvements) or an innovation which incorporates northern technologies. The technology thus discovered slightly differs from the current southern trajectory though is not quite yet the northern technological trajectory. We therefore qualify this technology trajectory as a transitional trajectory.

Effectively southern firms do not end up discovering new technologies per se when they reach the northern trajectory, however this assumption is concurrent with the way innovations works for developing countries as described by Cimoli et al. (2011) or Lall (1992), when they find that the innovation process consist mostly in finding ways to catch up with existing technologies.

Transitioning thus consists in improvements on current technologies while integrating some new elements discovered by northern technologies. Therefore when such discoveries are made, it is difficult to consider that the technology is the start of a new paradigm. This is why when those discoveries are made, it represents a change in paradigm, but the technology discovered is situated at around the same point as the firm was on the previous trajectory. Basically the innovation is seen as a step gained over the previous version, plus a more qualitative improvement which sets that particular version. In essence, those transitional discoveries can be qualified as a mutation of the technology. Figure 3.2 below represents an example of technological catching up incorporating those transitional discoveries. Between the two main trajectories, i.e. the starting ones for the northern and southern firms, a number of transitional trajectories exist. Southern firms have made discoveries (incremental innovation) all along the primary southern trajectory, up until they have started incorporating knowledge from northern technologies and made those semi-radical innovations which caused a change in technological paradigm. As more mutations of the technology are discovered (the pink triangles), the southern firms move up in technological trajectory until they have reached the northern trajectory. This represents how gradual the radical innovation process is for the South, and how innovation can lead to catching-up.

In the model, the number of transitional trajectories is a parameter which can be modified to reflect the actual gap between North and South. When running the simulations, we keep the gap between trajectories fixed and constant between each trajectory, whether main or transitional, while modifying the number of transitional trajectories. Therefore the

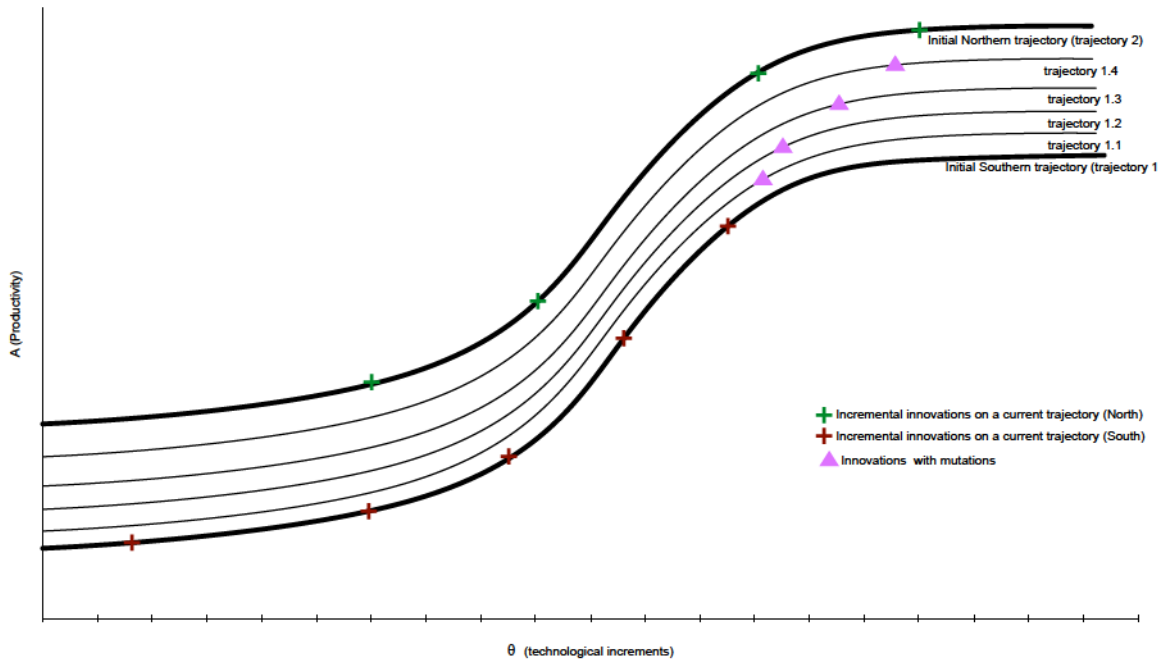


Figure 3.2: *Innovations on transitional trajectory: How the South catches up to the North*

gap between North and South is given by the number of transitional trajectories between the starting trajectories. The larger the gap, the more sophisticated the northern technology is comparably to the current southern one and therefore requires a more complex catching up process.

Another point to mention is that in this model, since the focus is on the South catching up to the North, the North will not be able to make radical innovations, as we consider the North technology to be the highest level possible in the industry. This assumption may be relaxed by allowing the North to make radical discoveries. The logic would there have it that if such radical discoveries are made, the North would effectively be discovering a new path, but they would then have to start from the beginning of this new path, since there are no superior technologies known, and this innovation would be exploratory.

2.5 Skills, experience and training workers

The system of skills and experience is reminiscent of Nelson (2008): *“Training provides a substantial base for learning by doing and using.”*

Since this first model focuses on labour turnover as the main channel of technological transfer, an important aspect of this model concerns the interactions between the labour force and technology. Here those interactions are modelled through the skills system.

Depending on the technologies learned and their proficiency, workers have a level of skills which will determine their productivity. Therefore, there are two aspects to consider here: the first is how those technologies are learned and secondly how they affect the productivity of the worker. The learning aspect is the first step in transferring knowledge through workers, that is workers need to acquire the technology before they can transfer it to firms. The productivity of a particular worker given her skill level is relevant because it affects the decision of the firm when it comes to selecting candidates. This point is detailed in section 6 while presenting the labour market. First we will present how the skill level is calculated, then we will look into how workers acquire those technologies and finally how the productivity of the worker and the firm interacts with this skill level and the technologies mastered by the worker.

2.5.1 Determining the skill level of a worker

The skill level of a worker is direct reflection of her experience working in the industry. The more experience a worker has, the higher the skill level. There is also a qualitative criteria, that working on more sophisticated technologies should give the worker a higher skill level. The value of a worker to a firm and the wages they may expect to earn is directly linked to their skills and experience. They are an important aspect of this model for two reasons: skills will dictate how well a worker may perform in a given setting. Additionally, since labour turnover is considered a means of transferring knowledge, the knowledge acquired working for other firms may hold value for future employers not only for productivity purposes but also for research purposes.

2.5.2 Worker's experience: building a CV

In this model, the skill level of a worker is determined by the knowledge of technologies acquired and the experience (measured in units of time, where one period equals one unit) using each of these. At first every worker starts with no knowledge of any technologies. This knowledge is obtained by working in a firm, where the worker is trained to use the technology. Once the training period is finished the technology is considered acquired for the worker, and working on it will increase her experience level in it. Formally, each worker h has a curriculum vitae (henceforth noted CV) matrix which stores her work

history:

$$CV_h = \begin{pmatrix} \theta_1 & \theta_2 & \dots \\ p_1 & p_2 & \dots \\ exp_1 & exp_2 & \dots \end{pmatrix} \quad (3.2)$$

where each technology (θ_j, p_j) with $j \in \{1, 2, 3, \dots\}$ is identified by a θ on a trajectory p and exp denotes the experience working on that particular technology. Once the worker has learned a technology j (θ_j, p_j) , the level of exp_j grows by 1 unit each period the worker is using this technology. While the worker is learning the technology, she is using the closest technology that she knows to that of her employer on the same trajectory, so her experience level of this technology grows.

Initially, we assume that every worker knows nothing, this means that their knowledge of each technological paradigm is limited to the initial trajectory $\theta = 1$ (including the transitional trajectories).

This will allow us to calculate a technological distance (see equation 3.5) for the worker with any firm, regardless of the trajectory it is currently on. Also it means that even if the worker becomes highly technologically advanced exclusively on, for example, trajectory 1 and they encounter a firm i working on trajectory 3 at $\theta_i = 50$, then the worker's technological distance with that firm is 50, because essentially the worker knows nothing of that technological path, and her eventual high knowledge of another path is not useful on another technological trajectory. Her high experience however will serve her to be more efficient working on that technology.

2.5.3 Computing the skill level

The skill level is dependent on the experience the worker has in the industry and to some extent on the level of education she received. Inactivity also affects negatively the skill level. Each worker start with a base skill level $baseskill = \frac{edu_h}{edu_{NAT}}$. We note that if the model includes population growth, that is new workers which join the industry later on, this level of basic skill changes and becomes :

$$baseskill_t = \frac{edu_h}{edu_{NAT}} * \bar{skill}_t$$

This reflects the idea that as technology advances and the skill level with it, the level of education grows in the country and new workers join the market with more competitive skills².

The skill level of each worker is updated at each period. Two situations may occur. If the worker is unemployed then the skill level decreases by a discount factor δ_{skill} :

$$skill_{h,t} = (1 - \delta_{skill})skill_{h,t-1} \quad (3.3)$$

If the worker h is employed by a firm i then skill level increases by the extra experience gained. The extra experience is given by $a_{skills} * \ln((\theta_{h,i} + 1) * (p_i + 1))$, where a_{skills} is a factor which represents the importance of the actual experience. $\theta_{h,i}$ corresponds to the technology currently used by the worker, which is the closest technology known by the worker to that of the firm on the trajectory where the firm is situated. Usually this θ should be that of the firm, unless the worker has not learned the technology of the firm yet. Thus the skill level is thus:

$$skill_{h,t} = skill_{h,t-1} + a_{skills} * \ln((\theta_{h,i} + 1) * (p_i + 1)) \quad (3.4)$$

We note that technologies on higher trajectories bring in a higher level of skill for the worker, this is due to the more complex technologies present on higher trajectories.

In section 2.5.5, we explain a way of interpreting this mode of computing the skill level, that is how the skill level affects the proficiency of a worker.

2.5.4 Training workers

When a new worker is recruited by a firm, she must use the technology used by the firm regardless of her other skills. It is often the case that a new worker will need to adapt to the production process of her new employer. Unless the worker has worked in a firm using the exact same technology in the past, she will need some amount of training in order to learn the technology used by the firm. It is essential for a firm to train its workers, as mismatch in skills can cause inefficiencies in the production process (Acemoglu and Zilibotti (2001)). The new worker is subject to a training period τ at the start of her employment in order

²Those new workers do incur a penalty due to their lack of experience, they will require longer training at the recruiting firm.

to assimilate the technology. The time needed for a worker to learn this new technology depends on two parameters:

- the education level (edu_h): Better educated workers will learn faster.
- the technological distance: If a worker knows a technology which is almost similar to that of the firm, then the adaptation process should be faster. The distance that is calculated by taking the firm's current θ and the worker's closest θ on the same trajectory as the firm's on her CV.

2.5.4.1 Technological distance A final point to mention regarding the technology space is how the concept of technological distance exists in this model. Here, the technological distance may only be computed for technologies within the same trajectories. This is because we consider that technologies on different paths may not be directly compared as the difference in paradigms is more qualitative than quantitative. Therefore the distance is unidimensional. There is the distance on a given trajectory between two versions j_1 and j_2 of the technology is calculated as:

$$\Delta_{j_1, j_2} = |\theta_{j_1} - \theta_{j_2}| \quad (3.5)$$

There is a maximum duration possible of training³ which is set at 20 periods, which corresponds to the duration of training needed if the worker had a technological distance of 20 with her employer, given an average level of education. This maximum can be changed, the idea remains that above a certain technological distance, the technology is perceived as unknown and requires a complete training for the worker, which is set at 20 periods.

The initial time $\tau_{h,i}$ needed for training is thus calculated:

$$\tau_{h,i} = \min\left(\frac{edu_{NAT}}{edu_h} * \Delta_{i,h}, 20\right) \quad (3.6)$$

where $\Delta_{i,h}$ is the technological distance between the firm's technology and the closest inferior technology known by the worker on the same path as the employer.

Each period the worker is being trained by the firm, the $\tau_{h,i}$ reduces by one unit. Once $\tau_{h,i} \leq 0$, the technology is learned and added to the worker's CV. If during the training

³This limit is necessary to eliminate overflow in numerical computations

period, the firm changes technology, the worker must first complete the training on the previous technology before starting to learn a new one. If the worker switches firms while in training then the technology is not learned.

2.5.5 Workers' Productivity

In this model, the worker's productivity is dependent upon matching the firm's technology and the corresponding skill level. Depending on the technology used by the firm, a worker can be more or less productive depending on her level of skill, but also depending on her specific skills and experience.

The technology the firm uses is given by θ_i on a given trajectory, and to each θ is associated a maximum productivity level. The actual productivity level of the firm will get closer to its maximum if its workers are trained to use this technology (there is a technology in their CV that matches that of the firm) and if the employees are highly skilled. The productivity level will never exceed this maximum. That is even if workers are extremely skilled, their efficiency is limited by the technology of the firm.

The productivity of the firm is thus dependent on the productivity of its workers. Workers will be less productive if they have not yet learned the technology, thus a mismatch of technology will cause a decline in the worker's productivity compared to the potential maximum productivity of the firm. Similarly, if the worker is not sufficiently skilled, her productivity will also decline.

Say the firm has θ_i^P then its maximum productivity level is $A_i^{max}(\theta_i^P)$. Each worker of the firm will have an effective productivity level $A_{h,i}$ which is a function of her skill and matching of the technologies.

Mismatch of the technologies discounts the maximum productivity of the firm by a mismatch factor $\gamma_{h,i} \in [0, 1]$ which is increasing with the distance of technologies and mismatch of paths. This mismatch of technology notably exists when the workers are in training and thus use an inferior technology. This $\gamma_{h,i}$ is a factor of the technological distance between the firm and the worker $\Delta_{h,i}$ and a scaling parameter a_γ chosen exogenously. The higher the distance, the smaller the factor (thus affecting negatively effective productivity). The greater a_γ , the greater the impact of technological distance on the worker's effective productivity. Similarly to the computing of training time τ , there exists a maximum distance which caps the γ of the worker. Here we suppose that if the technologi-

cal distance is above 40, there is no further penalty incurred in the worker's productivity. It makes virtually no difference if the distance is higher in terms of technological mismatch between the firm and the worker. For $a_\gamma = 0.1$ this roughly means that the minimum this γ will reach is 0.02.

$$\gamma_{h,i} = e^{(-a_\gamma \max(\Delta_{h,i}, 40))} \quad (3.7)$$

The second factor to influence actual productivity of the worker is her skill level. The more skilled a worker is the more efficient she is. This is to say that it is not enough to master the technology, one also needs skills to exploit it to its full potential. Therefore, we define a second skill factor $\psi_{h,i} \in [0, 1]$ which increases with skill and also depends on the technology used by the firm, so that if a firm uses a rather high technology on its chosen path, a higher level of skills should be required.

We define the skill factor as:

$$\psi_{h,i} = \min\left(1, \frac{\text{skill}_h}{\theta_i * p_i}\right) \quad (3.8)$$

This function indicates that if the skill level is sufficiently high, there will not be a loss in productivity of the worker. However the level of skill required to achieve this point is dependent on the trajectory as well as technology of the firm. Higher trajectories require a higher level of skill to be efficient while working on them. The specification of this factor combined with how skills are computed can help to interpret this skill factor.

Consider a worker who has only ever worked for the same firm with the same technology (which we assume in this case will not evolve) for n period. Her skill level would thus be:

$$\text{skill}_h = n * a_{\text{skills}} * \ln((\theta_i + 1) * (p_i + 1))$$

Her skill factor would be :

$$\psi_{h,i} = \frac{n * a_{\text{skills}} * \ln((\theta_i + 1) * (p_i + 1))}{\theta_i * p_i}$$

For her to be efficient while working at the firm, that is $\psi_{h,i} = 1$, she would need to have

$$n * a_{\text{skills}} * \ln((\theta_i + 1) * (p_i + 1)) = \theta_i * p_i$$

which can be rewritten as :

$$n = \frac{\theta_i * p_i}{a_{skills} * \ln((\theta_i + 1) * (p_i + 1))}$$

Therefore we can determine the number of periods the worker need to have worked in order to achieve full efficiency on the technology. We note that this number increases with the technology of the firm. Thus another interpretation that can be given to the skill-factor is that the worker needs sufficiently experienced to be efficient. If the worker has worked with only lower technologies in the past, then skill efficiency would require that the worker has accumulated even more experience. Conversely, if the worker has worked with more sophisticated technologies, then the amount of experience required will be less. This interpretation also helps calibrate the model, as we can investigate which scaling factors would be more appropriate in the context to ensure that the progression of skills is adapted to the progression of technology.

Once $\gamma_{h,i}$ and $\psi_{h,i}$ are determined, we can compute the effective productivity of the worker by averaging the two factors. With such a specification, the productivity of the worker cannot exceed the maximum potential productivity of the firm.

$$A_{h,i} = \frac{\gamma_{h,i} + \psi_{h,i}}{2} * A_i^{max}(\theta_i^p) \quad (3.9)$$

The actual level of productivity A_i of the firm is the mean effective productivity of all its workers $h \in H_i$, where H_i is the set of firm i 's employees. L_i is the number of employees

$$A_i = \frac{\sum_{h \in H_i} A_{h,i}}{L_i} \quad (3.10)$$

2.6 The labour market

In this particular industry the production inputs (noted L_i for the labour force, and K_i for the capital) are complementary. Firms buy capital which requires a labour force to operate it. Thus capital here will refer to production equipment of the firm. Each unit of capital may be exploited by α workers, α being an exogenous parameter. If capital depreciates, this signifies that the equipment is losing effectiveness and thus less workers are needed, as machines do not work to the best of their ability. If there is investment in capital, then the firm is expanding and will need to recruit more workers to use it, thus creating jobs through capital investments. Except for the initial period, the decision to hire workers takes place at the beginning of each period and usually immediately follows the decision to invest (or not) in capital made at the previous period. Therefore any decision regarding hiring workers depends on the state of the firm's capital. The labour market in this model works through the following steps:

1. Firms determine if they have job vacancies: this will depend on their current workforce, capital level, price and wages.
2. Workers search for jobs and apply to a limited scope of job vacancies.
3. Firms review their applicants and select the best suited candidate. They make them a job offer.
4. Applicants review all their job offers and accept the highest paying one, provided the offered wage is above their reservation wage.

2.6.1 Job vacancies and dismissal of workers

At the beginning of each period, the firm determines how many workers it needs and/or can hire, and in some cases if it needs to let go of current workers. Three criteria are accounted for. First, is how many employees does the firm currently have⁴. This is fairly straightforward, though it needs to be counted, as current workers are bound to the firm by contracts, which means that they cannot be arbitrarily fired to make room for new/better workers.

⁴We remove from this number contracts finishing at that current period.

The second criterion is how many workers can the firm afford. Affordability is based on the mean wage paid by the firm, this is an indicator of the cost of each unit of labour force. To determine how many workers the firm can afford, we look at the firms' current equity and the expected sales. The expected sales is calculated by using the average income from sales of firms of a similar type (i.e. Northern or Southern firms). Let L_A be the number of workers the firm can afford to have:

$$L_A = \frac{\text{equity}_i + \text{sales}^e}{\text{wages}_i}$$

Using the average sales from similar firms allows for firms that have not been producing for economic reasons to attempt coming back to the market when market conditions become more favourable. In the model, the firm can only let go of its currently contracted employees for economic reasons. Therefore, if its current workforce exceeds the anticipated affordable size of workforce, the firm will have to let go of a number of employees (the difference between its current workforce and the affordable one). If the firm can afford more workers than it currently has, then the firm determines the ideal number of workers, and if this number is greater than the current workforce, then the firm tries to hire extra workers, up until the ideal size is reached or it can no longer afford anymore workers, whichever comes first.

As labour is complementary to capital, and each capital unit can be used by a set number of workers α , there is no need to hire more workers if all capital units are saturated. If we have $\alpha K_i \geq L_i$, then some capital units are not being exploited to their full potential, so the firm can consider increasing its workforce. However, as we will see in the next section on production, it is not possible to reduce capital units other than through usual depreciation. If we find that $\alpha K_i > L_i$, it could be the case that the firm has extra units of capital that will not be of use. Therefore the firm needs to determine the best number of employees given market conditions.^{5 6}

Now to determine the best number of employees, firms look at expected profit, and

⁵For the initial period of the model simulations, the firm chooses to hire exactly αK_i workers.

⁶We note that if αK_i is not an integer then, as workers are indivisible, the number of workers required to fully exploit the capital units is $\lceil \alpha K_i \rceil$. This extra worker will produce less units, though will still need to be paid a full salary. This extra worker is thus more costly than others. Nevertheless, we choose to have as a decision rule firms electing to hire this extra worker. The reasoning is that since firms post as many vacancies as they have and workers have the ability to reject offers, it is possible that the firm ends up not hiring this extra worker (and even less workers than that, should they be so unlucky on the job market).

determine from there on the number of employees corresponding to the highest expected profit. Computing expected profits is based on variables observable by the firm, such as its previous price, observed productivity and also their previous performance on the market. This is detailed in the next section. Though since hiring workers takes place right after investing in capital, the decision to hire is linked to the capital investment decision. While making that decision to invest in capital, the firm had determined a desired size for the firm given the current market conditions. This size corresponds to a desired amount of capital K^* and its matching size of the labour force L^* that corresponds exactly to αK^* . Regarding this optimal size, the firm can be three different settings: either it was unable to expand capital to K^* and thus has less than the desired amount of capital (1), or it has exactly the desired amount (2) or it has too much capital (3), and since capital may not be resold, the firm will have to operate at K^* , rendering the extra units of capital it possess useless.

Since the profit function is concave, in the first setting the firm will want to have exactly as much labour as its capital will allow. Even if the optimal size of the firm is larger, there would be no point in hiring more workers than the current capital capacity allows for since these extra workers would not be of any use to the firm. In the second and third setting the firm would want to hire αK^* workers. Specifically for the third setting, there would be no reason to hire more workers, as the unused capital is sunk costless, whereas hiring more workers would yield lower profits for the firm.

Thus we define L^* the desired quantity of workers given the level of capital of the firm.

$$L_{i,t}^* = \min(\alpha K_{i,t}^*, \alpha K_{i,t}) \quad (3.11)$$

The actual desired amount of workers is $\lceil L_{i,t}^* \rceil$

Once this number is computed, the firm assesses how many workers it should hire (or dismiss) depending on affordability and the current state of the workforce.

To summarise the different possible situations, let us name L_A the quantity of workers the firm can afford, L^* the optimal number of workers given the current level of capital and C_w the current numbers of contracted employees (the firm does not have visibility on workers who might break their current contract this period. Table 3.1 presents the number of vacancies and or people to fire given the different configurations a firm can be in.

Configuration	Vacancies	Dismissals
$L_A > L^* > C_w$	$L^* - C_w$	0
$L_A > C_w > L^*$	0	0
$C_w > L_A > L^*$	0	$C_w - L_A$
$C_w > L^* > L_A$	0	$C_w - L_A$
$L^* > L_A > C_w$	$L_A - C_w$	0
$L^* > C_w > L_A$	0	$C_w - L_A$

Table 3.1: *Determining job vacancies under different configurations*

2.6.2 Wages

2.6.3 Recruitment strategy and Wages offered

As in Dawid et al. (2013), the wage effectively paid to each worker will depend on their productivity. In our model, the productivity of the worker depends on her technological distance with the firm, and her skill level. Since there is training offered by the firm to their workers to eliminate the technological distance we can assume that in the long term the initial distance between the firm and the worker does not matter as much. Therefore firms will look into hiring the most skilled individuals. This is strategy can be effective in the short and long run. In the short run, highly skilled individuals are more likely to know a larger set of technology, and therefore are more likely to have a shorter technological distance. Their high level should also make them more future-proof as the firm advances in technology, they will be able to be more effective than less skilled individuals. Finally, since technological transfers happen through the labour force in this model, having better skilled individuals increases the possibility of having workers with knowledge of superior technologies.

Wages offered are based on the expected productivity of the worker. The firms are not able to compute the γ and ψ factor of each worker. They estimate the productivity of the worker by looking at the skill level of the candidate and comparing with the current average level of skills within the firm. They determine $A_{i,h}^e$ the expected productivity of the worker, based on the current productivity observed of the firm i as :

$$A_{i,h}^e = A_{t,i} * \frac{skills_h}{skills_i}$$

This calculation may be overly simplistic in the sense that wages offered might overpay highly skilled individuals as the productivity of the firm is capped by its current maximum

level a technology can provide. However the higher wages are necessary for southern firms trying to recruit highly skilled individuals who would otherwise choose to work for a northern firm. Furthermore, this higher wage can be seen as an investment for the future: the firm would have a more capable worker and a worker with potentially superior technologies.

Wages are based on a "base wage" w_{base} which is set exogenously for the whole industry. Then firms adapt this wage with the expected productivity level of the worker. Thus, her wage effectively offered would be $w_{h,i} = w_{base} * (1 + A_{h,i}^e)$.

The level of wages in the country will grow with the average productivity. As technology advances and workers learn and become more productive, the average wage is expected to grow. Similarly, because Northern firms start with a higher productivity due to being on the advanced technological path, they are able to offer higher wages, and thus attract the best workers..

Similar to Dawid et al. (2013), we also include the possibility for firms to adjust the wages offered when not enough candidates accept their job offers. If the firm fails to recruit the desired number of workers, then this would mean that the offers made have been too low. Therefore, the firm would need to adjust the wage offered by increasing it at the next period. Conversely, if the firm does manage to recruit the exact number of desired workers, then the firm could try and lower the offers next period so as to diminish costs. Should this strategy fail, then the firm would have to re-increase wages. The idea is that when there is full employment, and workers become difficult to recruit, firms need to make their offers more attractive. Conversely, when unemployment is high and firms have no trouble recruiting, then the offers may be decreased.

To model this wage adaptation scheme, we define exogenously three variables: a multiplier variable m_{wage} (set at 0.05), and a minimum and maximum cap for the adapting the wages. These are set exogenously. The minimum and maximum caps ensure that wages do not explode (for the maximum cap) and do not decrease too much (minimum cap). The minimum cap can be interpreted as the level of flexibility in wages on this labour market, whereas the maximum cap is a more strategic variable, if set too high, wages may explode which would be costly for the firm and recovery might be long which would hinder the firm's progress. Firms have a counter $fails_i$ initially set at zero, which grows by one unit every period when the firm fails to recruit the desired number of workers (either because

of scarcity in labour supply, or uncompetitive wages). This counter decreases by one unit if recruitment has been successful. The counter is capped by the minimum and maximum cap. The multiplier takes the following value :

$$\text{multiplier} = (1 + m_{wage} * fails_i)$$

Since m_{wage} is set at 0.05, this means that if the firm has a counter equals to 2, the multiplier takes the value 1.10, meaning the firm will increase their offers by 10%. Conversely if the counter takes the value -3, the multiplier would take the value 0.85, so a decrease of 15% on offers made.

We can thus determine the actual wage offered by the firm to a given candidate:

$$w_{i,h,t}^O = (1 + A_{h,i,t}^e) * w_{base} * (1 + m_{wage} * fails_{i,t}) \quad (3.12)$$

We note that the offer is based on the productivity of the applicant at the time of recruitment thus the use of $A_{h,i,t}^e$. Naturally, at the end of the contract it would appear that due to the experience and skills acquired, the worker could expect to be earning higher wages in their next job.

2.6.4 Reservation wages

Workers have reservation wages w_h^{res} below which they would decline the offer. The reservation wages are not known by the firms. Unemployed workers expect to earn a wage with a level comparable to that of their previous employment. However, as their period of unemployment increases, their reservation wage decreases by a δ_{wage} each period the worker remains unemployed. The minimum level this reservation wage may attain is that of unemployment benefits. So this gives us:

$$w_{h,t}^{res} = \max(\delta_{wage} * w_h^{t-1}, \text{welfare}) \quad (3.13)$$

Initially, all workers have a reservation wage equal to that of welfare. Unemployment benefits is defined as a small percentage of the average wage of the active population. It is financed by the government, through a taxation system (see next section). As its actions

are limited here, we chose not to represent it as a full actor of the model.⁷

2.6.5 Making and receiving offers

The number of job openings having been determined, unemployed workers start applying to positions. Each worker only sees a limited number of job opening defined by "market visibility" parameter set exogenously. Say there is poor visibility in the job market, this would imply that workers may only see 20% of firms with job openings. Furthermore, which jobs are visible to whom is random. So if 10 firms have openings, each worker will only apply to 2 of them.

Employed workers may also start to look for jobs. The probability that a currently employed worker will look for a job at another company (cannot apply to her current one) is $\frac{\text{time left on contract}}{\text{contract length}}$ so that the closer to the end of their contract employees are, the more likely they are to look for jobs elsewhere.

Also, workers whose contract just ended, and whose firm is advertising for job vacancies are automatically considered for reemployment, though they are in competition with other candidates and are able to get a new wage level due to their now increased experience and skill.

Firms then receive applications and evaluate them. For each vacancy they have, they select the best candidate, and make her an offer. Firms have the possibility to observe the skill level of the applicant but not her education quality. As we mentioned the decision on who to hire rests on the skill level.

Therefore, if faced with multiple applicants, the firm chooses the candidate with the highest skill level. Firms recruit on the skill basis solely because it captures the The offer made by the firm is the wage determined in the subsection above, which is:

$$w_{i,h,t}^O = (1 + A_{h,i,t}^e) * w_{base} * (1 + m_{wage} * fails_{i,t})$$

Workers are attracted to the highest wage. They do not really account for the potential of the firm (they cannot realistically have a true visibility on this). Thus, if a worker receives multiple job offers, she will pick the highest paid one, provided it is above her reservation wage.

⁷If unemployment benefits were not financed by the state, this extra revenue in the demand could be interpreted as workers working in another, lower paying sector, with the wage level increasing as standards of living are raised in the country due to technological progress.

2.6.6 Contracts

Once a job offer is accepted, the worker is bound to the firm by a contract. The contract stipulates how long the worker will work for and at which wage, as specified in the job offer.

We assume here that all contracts have the same length, as given by an exogenous parameter. The contract length corresponds to how long the firm is bound to the worker. This parameter illustrates the degree of rigidity of the labour market in the country. Therefore a rather rigid labour market will have a long default contract length, whereas a more flexible labour market will have shorter contracts. This is an important characteristic of the model to observe, as with longer contracts, workers should be able to acquire more skills and thus have better chance of transferring knowledge. On the other hand long contracts may affect the firm's economic performance as they are less able to adapt to changing market conditions and might end up with an undesirable workforce, and less inclined to receive new workers as those are bound by long contracts. Therefore it would be an interesting parameter to study both in regards to technological transfers and economic performance.

Contracts may also break randomly with a very low probability, in which case the worker ends up in the unemployed pool. Contracts may be freely broken by workers, if they find a better paying job. The firm on the other hand may only fire currently contracted workers for economic reasons as discussed in subsection 6.1. Once firms have decided on the number of workers to dismiss, the choice of who to fire can be made according different criteria. One could consider firing newer worker first, or less skilled ones or even less productive ones. The rule retained here is the wage-productivity ratio rule. For every employee, the firm computes the ratio $\frac{wage_h}{A_{i,h}}$. The higher this ratio, the more costly the worker is to the firm in terms of production costs. Therefore the firm chooses to dismiss the workers with the highest ratio.

2.7 Production, demand and profits

Once the labour force is set, the firm proceeds to training its workers as described in section 5.2. which will allow for determining the productivity of workers this period, and thus the firm will be ready to move on to producing the good and selling it on the goods market. Firms start with a set amount of *equity* which is the same for all firms. Northern

firms however can start with a bonus amount which would represent the fact that northern firms do start with some financial advantages. The equity serves to finance mainly the initial periods of the model as firm get adjusted to the market. Firms also start by recruiting exactly αK_i workers which can be initially costly. The starting equity mainly serves as a way to finance this. After this initial periods, firms are expected to use profits to finance their operations and investments.

2.7.1 Production

Firms produce a homogenous good. The good is perishable, which means firms are not able to keep stock for the next period, and any unsold good is lost. The good is produced using two inputs: capital (the equipment) and labour (used to operate said equipment). Labour and capital are complimentary factors: labour needs machines to operate, and the machines (capital unit) can only be used by a maximum of α workers. Firms have diminishing returns when it comes to the scale of their operations, that is the bigger the firm (as measured by units of capital and labour), marginal production decreases. With bigger operations, the more likely it is that their will be failures in the production process. Also larger firms are more costly to manage, which affects the overall productivity.

Thus the quantity Q_i produced is determined by :

$$Q_i = A_i * \min(L_i; \alpha K_i)^\beta \quad (3.14)$$

where L_i is the number of workers employed by the firm, K_i the number of of capital units held by the firm and α the maximum number of workers per unit of capital. We have $0 < \beta < 1$ to allow for decreasing returns of production factors. The more capital and thus labour a firm possess, the larger its size. The shape and behaviour of this type of production function is presented in appendix E. Firms start with a given number of capital units (*basecapital*). This *basecapital* is a parameter of the model and all firms have the same capital level at the beginning. There is also a northern firm advantage where northern firms also start with a supplementary number of units. The size of this advantage can vary to test whether the size of northern MNEs settling in developing country can affect the local industry. Capital decays by a factor $\delta_{capital}$ each period. Capital in the base model

has no periodic (i.e. maintenance) costs⁸.

There is however a replacement cost: As capital depreciates, the production process loses some efficiency. Firms have the possibility to renew the capital at a cost ck . The replacement costs evolves with price levels thus reflecting inflation in other sectors.

2.8 Pricing Strategy

Firms here select their own prices so as to ensure they make a profit. This means that they look at their average total costs (ATC_i) and charge a price with a markup (μ). The markup is a fixed parameter of the model, though we can make it possible for the firm to adjust the markup as their pricing strategy. In the basic configuration of the model however, we keep it fix to simplify analysis. The base markup is set at 40%. The average total cost is given by (assuming $L_i \leq \alpha K_i$):

$$ATC_i = \frac{L_i * \bar{wage}_i}{A_i * L_i^\beta} \quad (3.15)$$

The average total cost decreases with technology⁹ and increases with the size of the labour force, all else equals.

The price of the firm is thus: $price_{i,t} = (1 + \mu)ATC_{i,t}$. The markup is also meant to finance further investments in capital and R&D, as those are not accounted for in the total cost of the firm.

Once all the firms have set their prices, we compute the average price level in the economy which is the average price set by firms weighted by their quantity produced. The evolution of the price level in this economy is a reflection of two things: Price decreases with quantity produced. As firms become more efficient in their production process they are able to produce more with one unit of capital. So even if we add a unit cost on top of labour and capital costs, average cost will end up being decreasing with quantity produced over time. Price also increases with average income. Income is directly dependent on skills. With technology advancing and/or skills increasing over time because of experience, average income should increase over time too. The increase in wages is expected to reflect

⁸I did consider a model where there was an operational cost for capital, which resulted in a sunk costs for firms, and complicated labour hiring decisions due to that sunk cost. For simplicity we choose to forego them in this version.

⁹However an increase in technology should lead to an increase in wages and even labour force.

the increase in production as firms are responsible for training workers. Therefore with a such a specification price level should be expected to follow a rather tame trend.

If prices keep increasing then this would suggest that technological progress is insufficient and consumer welfare is diminishing.

2.8.1 Determining firm demand: the demand rationing rule

The goods demand that is addressed to firms is dependent on prices. Intuitively, firms with higher prices are bound to attract less consumers given that the good is homogenous. The firm producing with the lowest price is likely not able to fulfil all the demand, and therefore consumers will turn to other more expensive firms. Here every firm will receive a part of the demand as consumers are assumed to not have perfect visibility of the market. Therefore even the most expensive firm will receive some demand. The proportion of the demand that will turn to this particular firm will be lower. The rule to determine the share of the demand that goes to each firm is detailed below.

First, we need to establish the demand on the market. The amount available to be spent on goods is the sum of

- Workers' income after tax (the entirety of disposable income here is used, there is no savings from workers).
- Income from unemployment benefits paid to unemployed workers
- Dividends from profits received by households
- Unspent income from the previous period. Due to the rationing rule it is possible that some consumers which were looking to buy from a specific firm were rationed, and since there is no redistribution of the rationed demand. This unsatisfied demand would leave funds available to be spent at the next period.

Summing up those four elements gives us the total income dedicated to goods demand D_t for this period.

For each firm we compute the number of units $Q_t^{i,d}$ it would have been able to sell if it were alone on the market, with $Q_t^{i,d} = \frac{D_t}{price_{i,t}}$. This individual hypothetical demand is decreasing with the price of the firm. The share of the demand $s_{i,t}^d$ received by the firm is

given by :

$$s_{i,t}^d = \frac{Q_t^{i,d}}{\sum_i^n Q_t^{i,d}} \quad (3.16)$$

Thus the quantity (in units) demanded to the firm is given by $q_{i,t}^d$:

$$q_{i,t}^d = \frac{s_{i,t}^d * D_t}{price_{i,t}} \quad (3.17)$$

As we mentioned, it is possible that for a given firm the quantity demanded exceeds the quantity produced and therefore the firm would be in excess demand. This excess demand will not be satisfied at this period, though the income unspent will be part of the demand at the next period. Conversely in the case of excess supply, since the goods are perishable, they are lost (which can turn out to be costly for the firm), as excess demand is not redistributed. This means that in the industry there can be a mismatch between demand and supply, excess demand situations or waste through excess supply

2.9 Sales and Profits

The firm has established its price $price_{i,t}$, its supply ($q_{i,t}^s$), and the demand that is addressed to it ($q_{i,t}^d$).

From there, we can compute the income from sales the firm makes.

- If $q_{i,t}^s > q_{i,t}^d$, the firm is in excess supply and sells only $q_{i,t}^d$ units.
- If $q_{i,t}^s \leq q_{i,t}^d$, the firm can only sell as much as it produced, thus sells $q_{i,t}^s$ units. The firm faces excess demand.

Thus, the quantity sold $q_{i,t}$ by the firm is :

$$q_{i,t} = \min(q_{i,t}^s, q_{i,t}^d) \quad (3.18)$$

We note that excess supply happens mostly because prices are too high, and therefore it should be that firms either decrease their price or the production (to have decrease average costs)

Once production factors are in place, the firm produces and sells on the market at the price $price_{i,t}$ determined as explained in section 2.8.

We then compute the (gross) profits made by the firm:

$$\pi_{i,t} = price_{i,t} * q_{i,t} - \sum_{h|i} (wage_h) \quad (3.19)$$

Since it is possible to sell less units than what was produced, it is possible that despite the markup present in the firm's price, this profit becomes negative.

The profits are added to the firm's *equity*: $equity_t = equity_{t-1} + \pi_{i,t}$. This equity will be used to finance investment. We also compute taxation on the firms as described in the next subsection and subtract that from equity.

After taxes, the equity will be split into dividends paid to households, R&D investment and capital investment, and perhaps savings. The decision to invest in R&D precedes and is independent of potential capital investment.

As explained in the appendix E, since the production has decreasing returns to scale, the only way it can expand is by increasing their productivity. Therefore if a firm does not wish to invest in capital, this means that there is insufficient technological progress.

Dividends are paid to households after taxes. The dividend rate *dividend* is the same for all firms and is a fixed parameter. Since dividends are paid after taxes, this part of households income is not taxed.

2.10 Tax Structure

In this economy both firms and employed workers pay taxes. Firms pay taxes on their gross profits, whereas individuals pay taxes on their income from earned wages. Since there is only one type of spending by the government, the taxes only serve as a purpose to finance the payment of unemployments benefits. Therefore, the income the government needs to receive from taxes is solely indexed on its expenses. Theoretically, this means that in good periods with low unemployment, the tax burden will be quite low. The tax works as such :

- The government determines how much it needs to finance expenses and past unpaid debt. Call that amount $GDebt_t$
- A given proportion of this is to be paid by firms (T_f), and the rest by employed workers (T_W). So the taxes that are to be paid by firms in total amount to: $firmstax =$

$\min(T_f * GDebt_t, \sum_i \pi_{i,t})$ and for workers, we have $householdstax = \min(T_W * GDebt_t, \sum_h wage_{h,t})$

. The tax burden on either firms or workers may not exceed their total income, if that does happen, then the government would just be accumulating a debt that it should hope to repay later when more income is available in the economy

- To determine how much a firm pays in taxes, we compute the ratio of the firm's profit over total profits ($taxshare_i = \frac{\pi_{i,t}}{\sum_i \pi_{i,t}}$). A firm i thus pays in taxes: ($taxshare_i * firmstax$).
- A similar rule is applied to compute the taxes paid by a worker: $taxshare_h = \frac{wage_{h,t}}{\sum_h wage_{h,t}}$, and the tax paid by the worker h is ($taxshare_h * householdstax$).

This tax system allows for a potential study on the fiscal incentives a country may set to encourage the industry. That is it would allow to test the impact of tax breaks on either northern or southern firms on creating incentives for firm development. Similarly we can test taxing schemes that are favourable to firms, at the expense of a restricted demand. This could be another potential point to explore.

2.11 Capital Investment

Capital depreciates each period by a factor $\delta_{capital} < 1$ which corresponds to the wear and tear of equipment losing in production capabilities. Each firm thus sees their capital decrease over time. There is no second market for capital, so firm cannot resell units of capital themselves. After production, the quantity of capital the firm has is thus $(1 - \delta_{capital}) * K_{i,t}$. Firms have the possibility to replace or expand their capital by buying more units (divisible) of capital. They do so at the end of the period after having produced, sold, paid off taxes and invested in R&D. If there is equity left after all those steps, then the firm considers capital expansion. To simplify the model, we did not include a financial market, which would bring savings returns and thus make the decision to invest in capital an arbitrage decision between profits and financial returns.

Each unit of capital costs ck_t . This costs changes over the time. Capital unit costs evolve with the general price level. Each period we compute the general increase of average prices in the industry, and use this rate as an indicator for inflation in the economy. If prices rise in the industry, we suppose that they rise by a similar proportion in the capital goods sector. The inflation is computed by tracking the changes in prices over 5 periods.

In order to avoid strong prices fluctuations, we look at the average growth over the last 5 periods. Prices in the capital goods sector follow this inflation index. A similar logic applies in the R&D sector.

Firms then decide if and how much they are willing to invest in capital. They have to determine first the optimal size of the firm, that is how much capital they should be working with given the current market conditions. The factors the firm accounts for are :

- Observed productivity at this period ($A_{i,t}$)
- Price of the firm $price_{i,t}$
- Market position: it corresponds to a factor which accounts for the firm's eventual losses due to excess supply. We note $MP_{i,t} \in [0; 1]$ with $MP_{i,t} = \min(\frac{q_{i,t}^d}{q_{i,t}^s}, 1)$. If the firm was able to fulfil all its share of the demand (does not matter if the demand exceeds the firm's supply), this factor takes the value 1. Any underperformance diminishes this factor. The factor is an indicator for the firm that its market position, largely due to pricing (which is itself a result of costs of the firm), is subpar. This is important because since expected profits are calculated using the current firm price, a large price could motivate the firm to produce more when in reality it was unable to sell at that price, thus overestimating the expected sales.
- Labour costs of the firm, as computed by calculating the average wages paid by the firm $w\bar{a}ge_{i,t}$

We note that to compute the optimal size of the firm, the firm supposes that its labour force would correspond exactly to the amount of capital: $L_i = \alpha K_i$. The firm computes the expected profit by looking at expected sales given an amount of capital K_i . The expected income from sales is $price_{i,t} * A_{i,t} * (\alpha K_i)^\beta * MP_{i,t}$. We can see that if the firm has experienced excess supply its expectations of sales would be diminished. The expected costs is $\alpha K_i * w\bar{a}ges_{i,t}$, that is the firm supposes the wage level in the firm will not change. Thus the expected profits are :

$$\pi_{i,t+1}^e = price_{i,t} * A_{i,t} * (\alpha K_i)^\beta * MP_{i,t} - \alpha K_i * w\bar{a}ges_{i,t} \quad (3.20)$$

As this profits are concave with K due to decreasing returns, we can derive the desired

level of factors K_i^* with a simple first order condition :

$$K_i^* = \frac{1}{\alpha} \left(\frac{A_{i,t} \beta \text{price}_{i,t} MP_{i,t}}{w \bar{a} g e_{i,t}} \right)^{\frac{1}{1-\beta}} \quad (3.21)$$

And thus $L^* = \left(\frac{A_{i,t} \beta \text{price}_{i,t} MP_{i,t}}{w \bar{a} g e_{i,t}} \right)^{\frac{1}{1-\beta}}$ which is the desired labour force used to compute job vacancies (see section 5.1).

We can see that the desired size of the firm increases with productivity level and price level (and market position, so if firms have a high price, and still manage to sell out, but decreases with wage level. This is an important result for our model here because it highlights the idea that technological development (increase of A) is necessary to allow expansions of firms. This is coherent with an observation made by Nelson (2008) :

"High rates of investments, without effective assimilation inevitably results in low return to those investments, and little in the way of effective development."

The firm has now determined the desired level of capital and the workforce associated with it¹⁰. From this point, three situations are possible:

1. if $(1 - \delta_{capital}) * K_{i,t} = K_i^*$ then the level of capital is optimal and there is no need for capital investment.
2. if $(1 - \delta_{capital}) * K_{i,t} > K_i^*$ then the firm has too much capital. In this model there is no second hand capital market, therefore firms do not have the possibility to re-sell capital units. Since using capital is costless¹¹, firms will only adjust labour quantities to match desired production level (subject to contract rigidities and affordability). This means that some units of capital will not be used, though there is no opportunity cost associated with these unused factors.
3. if $(1 - \delta_{capital}) * K_{i,t} < K_i^*$ then the firm needs to invest in capital and recruit the appropriate workforce to operate it.

If firms find themselves in the third situation then, then they will try to invest in capital. Firms may only buy more capital units if they have sufficient equity. Therefore, once all other expenses have been accounted for and there is equity left, the firm sees how many

¹⁰This level is theoretical, because it is likely that the calculation does not result in a whole number

¹¹The appendix describes how this decision can be a bit more complicated in the presence of capital operational costs.

units it can afford. The firm buys as many as they can until K^* is reached or their equity runs out, whichever comes first.

Through these investment decisions, and with taxes and dividends, we do not expect firms to accumulate much equity, as most of the wealth ends up being reinvested. Therefore equity is not a indicator of wealth of the firm here. It would actually a negative sign if equity accumulates, as it would mean that firms are not investing sufficiently, most likely due to unfavourable market conditions.

2.12 R&D: Imitation and Innovation

2.12.1 R&D inputs

In order for the firm to make new discoveries or learn the technologies of competitors, they must conduct some research and development. Two main factors will affect the success of this endeavour: the size of the investment in R&D and the knowledge stock of the firm.

2.12.1.1 R&D resources The first factor corresponds to the size of the R&D efforts in real terms. As prices evolve, a given amount of expense should not be able to afford the same real level of R&D. Therefore we call R&D units the R&D effort in real terms. R&D units have a unit cost $rdcost_t$ which evolves with the prices in the economy, as per measured through prices in our final goods sector. As for the capital goods sector, the average growth rate of prices in the final goods sector over the course of five periods is computed to obtain an indicator for inflation. Thus each period, the cost of R&D ($rdcost_t$) is updated.

Firms spend $rdexp_{i,t}$ in R&D each period, which is thus converted in real terms, what we will call $rdunits_{i,t}$. R&D units are the resources available for the firms to conduct research. They represent researchers, machines and other tangible equipments enabling firms to conduct their research

Therefore for a given R&D effort at time t ($rdexp$), it represents in real terms:

$$rdunits_{i,t} = \frac{rdexp_{i,t}}{rdcost_t} \quad (3.22)$$

R&D units of firms are cumulative over time. The stock ($rdstock_t$) however depreciate at rate δ_{rd} .

The amount of resources for research and development available after investment is thus :

$$rdstock_t = (1 - \delta_{rd})rdstock_{t-1} + rdunits_{i,t} \quad (3.23)$$

2.12.1.2 Knowledge Stock of firms The second variable affecting the success of the research process is the knowledge stock of the firm $KS_{i,t}$. The knowledge stock is a synthetic variable which grows with every new technology learned by the firm, be it

through innovation or imitation, and whether it is used or not. Therefore if a firm has conducted sufficient R&D in the past, and discovered many technologies the knowledge stock would grow, compared to a firm that made no effort and kept on with one unique technology. As the knowledge stock is an aggregation of technologies, we choose to compute it in a way that is similar to another knowledge accumulation variable in the model, that is the *skills* variable of workers. Every technology j learned by the firm is defined by a θ_j on a trajectory p_j . Each technology j learned by the firm thus contribute to the knowledge stock by augmenting it by $\theta_j \times p_j$. Therefore the knowledge stock at time t becomes:

$$KS_{i,t} = KS_{i,t-1} + \sum_j (\ln(\theta_j + 1) * \ln(p_j + 1)) \quad (3.24)$$

where j is a technology learned at time t . Technically, only a maximum of two technologies may be learned at one period, one through innovation and one through imitation. Using such a simple aggregation still allows us to give greater value to technologies on higher paths, to give no value to starting technologies ($\theta = 0$) and give greater values to higher θ so as to capture the fact that an advanced technology is the accumulation of great knowledge. The initial knowledge stock is 1. If a firm has made many small incremental innovations then their accumulated knowledge stock might be higher than a firm which has made one unique significant innovation. All those small innovations are the product of research and relentless research efforts are thus rewarded by giving this type of firm an advantage when it comes to further research. This also means that there is an added incentive for the firm to invest in R&D and continue research efforts even if it does not lead to an immediate success. The building and consolidation of the knowledge stock has value in itself.

2.12.2 R&D Investment decision

The remaining question here is how much should the firm invest in R&D. Because only fruitful research improves the stock of knowledge, there is still an element of risk in the investment towards research. As we saw in section 2.11, increasing production capacity (that is capital increase) is not always the solution to increase profits due to diminishing returns. Improving productivity however does not have this costly effect

(although productivity does have diminishing increase as technology advances) and is necessary to allow the firm to expand. Increasing productivity can increase production without having to buy more capital. Both innovation and imitation require the use of the research and development laboratory. As the stock of R&D units decreases over time, it is necessary for the firm to keep on investing to maintain a minimum of research permitting these increase in productivity. If the firm wishes to maintain the size of their laboratory, as unit costs vary over the time, the total cost will vary for a same laboratory size.

Firms aim to invest a set percentage (r_{RD}) of their income from sales into R&D. As firms' economic progress is highly dependent upon their technological progress, they should seek to invest as much as they can. This desired expenditure is however a maximum amount. Their actual expense will be dependent upon their equity at the time. Given that capital investment follows R&D and that firms rely in part on their equity (on top of predicted sales) to expand their labour force, firms will seek to preserve part (proportion S_{RD}) of their equity while making their decision to invest in R&D. Therefore the R&D expenditure at time t is :

$$rdexp_{i,t} = \min(r_{RD} * sales_{i,t}, S_{RD} * equity_{i,t}) \quad \text{with } equity_{i,t} > 0 \quad (3.25)$$

If equity is negative, firms do not invest in R&D. Once the expenditure amount is set, firms update their R&D resources and proceed to research. They conduct both innovation and imitation at the same time.

2.12.3 Imitation

Firms may only imitate what they can observe. Technology being a costly advantage, firms normally go through length to shield their advantages and technological know how. There is no cooperation among firms in this because there is no apparent benefit to share their technology with their competitors. This implies that firms may not easily see what their competitors are doing, or which technology they know or have used in the past. This assumption comes from studies (Damijan et al. (2003b)) that find horizontal spillovers to be small in the short term because horizontal spillovers rest on the idea that technology is being shared to competitors, which firms are not likely to do.

Firms may technically imitate any existing technologies, although those on higher

paths and/or farther away have a lower chance of being imitated.

Firms need to be able to observe a technology in order to imitate it. As competitors are not exactly keen in sharing knowledge, this first step is thus already a hindrance in the process. This implies that for the firm seeking to imitate, this first step will be costly in terms of time spent trying to obtain useful information. For our model, the implication of this is that firms are only able to observe a limited number of competitors per period. Furthermore, since the imitation process requires observation of a technology, firms are only able to observe currently used technologies. The next chapter will look at expanding the scope of visible technologies by adding patents to the model, thus making even past technologies visible. Finally, since the model focuses on technological transfers through the labour force, a firm needs to have a worker who knows the observed technology in order to be aware of its existence and imitate it.

In the model we assume that firms can see a given small proportion of their competitors. This allows the firm to discover a vector of technologies to imitate. On this vector, the firm only keeps technologies that are better (a higher θ on the same current trajectory of the firm or any technology on a higher trajectory).

Imitation takes place in two steps: first we compute if imitation will be successful or not. If imitation is successful, then we select which technology will be imitated through a random weighted draw. The approach taken here in modelling this first step relies on the use of score function to account for all the factors affecting the chances of success of imitations. Through that score function we determine a parameter λ_i^{imi} that will serve as a poisson parameter.

2.12.3.1 Score function of the imitation parameter The following factors are accounted for in determining whether imitation will be a success :

- $score_i^{KS}$: knowledge stock of the firm: the more knowledge a firm has, the greater the chances of success. In order to get a measure of how high the level of knowledge stock is, we compare it to the rest of the firms.
 - If the knowledge stock is under the median level of the industry, then $score_i^{KS} = 0$
 - If the knowledge stock is between the median level of the industry and the third quartile of the industry, then $score_i^{KS} = 1$

- If the knowledge stock is above the third quartile of the industry then $score_i^{KS} = 2$
- $score_i^{RD}$: The existence of R&D resources. For imitation, it is not necessary to have too much R&D resources. The minimum is sufficient, and anything above will not hold much weight.
 - If the stock of R&D units is under 1, then $score_i^{RD} = 0$
 - If the stock of R&D units is at least 1, then $score_i^{RD} = 1$
- $score_i^{OPP}$: The imitation opportunities of the firm. The *opportunity* variable is the sum of the weights of each technology which are targets for imitation for the firm at a given period. The computation of weight is described below. The *opportunity* variable grows with the number of target technologies available to imitate, but decreases the farther away each target is from the firm's current technology. Basically if the firm is really technologically behind, then the opportunity for imitation will decrease given how complicated other technologies are in comparison, and how unlikely it is that the firm has workers with knowledge of these technologies. To compute the score a similar approach is taken to that of knowledge stock, in order to get a sense of the values obtained when calculating the opportunity variable. If the opportunity variable is null, then no imitation is possible.
 - If the opportunity is below the first quartile of the industry, then $score_i^{OPP} = 0$
 - If the opportunity is between the first quartile of the industry and the third quartile of the industry, then $score_i^{OPP} = 1$
 - If the opportunity is above the third quartile of the industry then $score_i^{OPP} = 2$

Once the score factors are computed, we calculate the poisson parameter λ_i^{imi}

$$\lambda_i^{imi} = \frac{score_i^{OPP} + score_i^{RD} + score_i^{KS}}{5} \quad (3.26)$$

The maximum this parameter can take is 1. We then proceed to random draw that follows a Poisson law of parameter λ_i^{imi} . If the draw returns 0, then the firms fails to imitate. In order to capture the difficulty of imitating significantly higher technologies, different thresholds for the Poisson draw were considered. If the random draw returns a

value of 1 or 2, then the imitation will be successful if the technology imitated is on the same trajectory as the firm, or on the transitional trajectory directly above the current one. To imitate any technology on any trajectory, that is including one that is two trajectories higher, the random draw must have return at least 3.

If a firm has $\lambda_i^{imi} = 1$, then the probability the imitation of a technology on a similar trajectory will be successful is 63%. This probability falls to about 2% for a technology on higher trajectories.

2.12.4 Computing imitation weights

Technologies should not have an equal chance of being imitated. Those containing higher chances (either because more steps or higher trajectory) should be more difficult to imitate. Once we have determined whether imitation will be successful or not, and what type of technologies will be imitated, we proceed to a random draw of technologies on the imitation scope of the firm. The draw is weighted. The weights are computed so as to capture the potential difficulties in imitating substantially more sophisticated technologies.

The weight of each technology on the scope is determined by :

- the number of trajectories in the industry: the higher the initial gap, the less likely a technology will be imitated. $\delta_{pmax} = p^{max} - p^{min}$
- the actual gap between the trajectories of the firm's current technology and the potential target technology j^{12}
- the distance between the firm's current technology and the target one: the farther apart the versions of the technologies are, the less likely the imitation will be ($\Delta_{i,j}$):
 $gapfactor = \frac{p^j - p^i}{\delta_{pmax}}$.
- The technological distance is compared to the maximum horizontal distance possible in order to have a horizontal distance measure comparable to that of the gap distance. The maximum distance is computed by taking the "theoretical maximum", which corresponds to the point where the logistic curve of the technological space starts to be asymptotical. Since our technological trajectories are drawn as "balanced" logistic curves, we consider the maximum theoretical distance to be the θ that is

¹²Since we only retain technologies on the current or higher path as targets, this factor cannot be negative

the double of the inflexion point of the logistic curve noted θ_0 . Thus the horizontal distance factor is: $distance\ factor = \frac{\Delta_{i,j}}{\theta_0}$

The weight for given technology j is :

$$weight_{i,j} = \frac{1}{(w_1 * gapfactor_{i,j} + 1)(w_2 * distancefactor_{i,j} + 1)} \quad (3.27)$$

where w_1 and w_2 are scaling parameters. The *opportunity* of a firm is also computed following this by summing up the weights obtained. Technologies farther away from the firm's current technology will have a lower weight and therefore a smaller chance of being imitated should the firm be successful in imitation.

When a firm has successfully imitated, the technology is added to the knowledge stock (see equation 3.24) whether or not the firm decides to use it. Usually if no innovation has been made at this period, but imitation is successful, they would go for the imitated technology. If both innovation and imitation are successful, then the firm picks which ever technology is the most sophisticated (higher trajectory or θ in this order) .

2.12.5 Innovation

When firms have some R&D resources available, they conduct some research in an attempt to innovate. Innovation is usually incremental, that is firms discover improvements of their current technologies on the current trajectory. As we explained in section 2.4.2, radical innovation in this model is the result of technological "mutations" that allow the southern firms to transition towards the northern technological trajectory in a gradual manner.

2.12.5.1 Incremental innovation Firms set up research labs in an attempt to improve on their technology and hope it will yield better productivity results than their current one. Incremental innovation in this model is represented as steps along a given trajectory.

A firm can improve its chances of successfully innovating if it has a greater knowledge stock and a greater investment in R&D. The more knowledge the firm has acquired in the past, the more efficient it will be at innovating. Efficiency in innovation means making a successful innovation but also making significant discoveries. It should be noted that advancing in technology is easier at the beginning of the trajectory. Therefore as technology

advances along the path, the likelihood of making more discoveries decreases. Furthermore, anticipating on the next chapter, the global knowledge, that the knowledge available to all firms also helps for innovation. In the basic version of the model, firms keep their knowledge to themselves, therefore the global knowledge is 0. The global knowledge stock is computed as the knowledge made public in the industry by firms (which is zero in this version of the model, since there is no mechanism for publicising knowledge).

In order to determine the number of steps the firm will make, we do random draw that follows a Poisson law. To determine the Poisson parameter, we establish a score function for innovation that will account for the factors influencing successful innovation. We thus define the Poisson parameter λ_i^{immo} for innovation as such:

- $score_i^\theta$: If the firm's technology is rather low in the trajectory, then its chances of innovation are increased. We define a critical point, which is the inflexion point of the logistic curve representing the technological space θ_0 .
 - If $\theta_i < \theta_0$ then $score_i^\theta = 1$
 - If $\theta_i \geq \theta_0$ then $score_i^\theta = 0$
- $score_i^{KSbis}$: knowledge stock of the firm: the more knowledge a firm has, the greater the chances of success. In order to get a measure of how high the level of knowledge stock is, we compare it to the rest of the firms. Because innovation is more difficult than imitation, the knowledge requirement is higher.
 - If the knowledge stock is under the third quartile of the industry, then $score_i^{KSbis} = 0$
 - If the knowledge stock is above the third quartile of the industry then $score_i^{KSbis} = 1$
- $score_i^{PKS}$ This is based on the knowledge made public. To compute the score here we look at how many better technologies than that of the firm have been made public. This knowledge can help the firms in their search for improvement (though this does not happen in this version).
 - If at least one better technology is made public then $score_i^{PKS} = 1$
 - If there no better technologies publicly known the $score_i^{PKS} = 0$

- $score_i^{RDbis}$: Finally, the amount of resources for R&D available influences innovation. Unlike imitation, greater expenses and resources make a difference. We note that if the firm has no R&D units, then innovation is not possible at all.
 - If the firm has more R&D units than the third quartile of the industry, then $score_i^{RDbis} = 1$
 - If the firm has less than the third quartile of the industry then $score_i^{RDbis} = 0$

The Poisson parameter for innovation is thus computed :

$$\lambda_i^{inno} = \frac{score_i^{KSbis} + score_i^{PKS} + score_i^{RDbis} + score_i^\theta}{4} \quad (3.28)$$

Once the parameter is computed we proceed to a random draw following a Poisson law. This will give us the number steps made by the firm. If the firm makes zero steps, we consider that the firm failed at innovating. The new technology discovered is $\theta_i + steps$.

Those innovations are incremental. In the following subsection we look at the possibility for firms to make radical discoveries in their innovations.

2.12.5.2 Radical innovation through technological transition As southern firms advance on their trajectory, the technologies get more sophisticated and firms start looking at new ways to improve their discoveries. These new innovations may contain some elements of radical changes. Following what has been discussed in section 2.4.2, the radical changes of southern firms follow a gradual process. Those small radical changes allow the firm to discover higher trajectories, which approach the technological frontier. As southern firms are competing with northern firms and are employing maybe former northern workers, they learn about new ways of production that are radically different from their current process. As they make new incremental discoveries, they start to incorporate those new techniques in their innovations, and the result is a new technology which is steps after their current technology that may also represent a change in technological trajectory. The innovation they made thus contain what we could qualify as a "mutation" of the trajectory.

Mutations can happen only if the incremental innovation has been successful. If it is the case, we look at the technology and see if it differs from the current trajectory. Having such mutations happen is quite scarce. A few factors facilitate the chances of this happening. A

third score function is used here to compute the probability of mutation through a Poisson parameter λ^{mut} .

- $score_i^{K^{Ster}}$: The firm must have a relatively high stock of knowledge comparatively to that of the other southern firms.
 - if the firm has a knowledge stock greater than the third quartile of the knowledge stock of all southern firms then $score_i^{K^{Ster}} = 1$
 - if the firm has a knowledge stock under than the third quartile of the knowledge stock of all southern firms then $score_i^{K^{Ster}} = 0$
- $score_i^{RD^{ter}}$: Firms must be using a high number of R&D units, a greater laboratory facilitates radical discoveries.
 - if the firm has less R&D units than that of the third quartile of the industry then $score_i^{RD^{ter}} = 0$
 - if the firm has more R&D units than that of the third quartile of the industry then $score_i^{RD^{ter}} = 1$
- $score_i^{labour}$: If some of the current employees have worked in a firm that is using technologies on superior trajectories, they can bring valuable input which increases the chances for the firm to incorporate those new elements in their innovation. This is how labour turnover can be a source of change for the South. The firm looks at the percentage of its labour force that has worked with such superior technologies.
 - if more than 10% of the firm's labour force has superior technological knowledge then $score_i^{labour} = 0$
 - if less than 10% of the firm's labour force has superior technological knowledge then $score_i^{labour} = 1$
- $score_i^{\theta}$: The level of the current technology θ must be quite high (we consider this to be somewhere on the concave part of the logistic curve basically). This implies that mutations do not really happen in the early stages of development. We define $\theta^{crit} = 1.5\theta_0$. This θ^{crit} is thus situated at around the third quarter of the technological path, which means, once firms are past this point, changes in trajectory are more likely.

- If $\theta_{i,t} > \theta^{crit}$, then $score_i^\theta = 1$
- Otherwise, $score_i^\theta = 0$
- $score_i^{PKSter}$ As with incremental innovation, the global knowledge stock also help firms moving on to higher trajectories.
 - If there is at least one published technology on superior trajectory, then $score_i^{PKSter} = 1$
 - Otherwise, if no higher technological trajectory are publicly known, $score_i^{GKSter} = 0$

We can thus compute the Poisson parameter λ_i^{mut} of the firm :

$$\lambda_i^{mut} = \frac{score_i^\theta + score_i^{KSter} + score_i^{RDter} + score_i^{labour} + score_i^{PKSter}}{5} \quad (3.29)$$

As we have done previously, we proceed to a random draw following a Poisson probability law. As we need to keep the probability of mutations happening rather low, we fixed the threshold at 4 for the mutation to happen, therefore if the draw reports a integer of 4 or greater, then the technology they discovered is considered to contain a "mutation", which means the firm can move on to the transitional trajectory immediately above their current one.

2.12.6 Adopting a new technology

Once innovation and/or has been successful, the firm evaluates which technology to adopt. They will by default chose to follow a technology on higher trajectory regardless of the value of θ . Lower θ on a higher path can only happen through imitation. If all the new technologies found are on the same trajectory, then the firm adopts whichever has the higher θ .

As a new technology is adopted, it is possible that firms will want to expand, since the optimal size of the firm is positively correlated with the technological level. This means firms might have incentives to invest more in capital, and at the next period they might want to hire more workers. A new technology also means that workers will have to be retrained. For an incremental innovation, the cost (in terms of loss of productivity) is low, as we expect current workers to have mastered similar technologies. For a radical innovation,

this cost is all the more important. Similarly if the new technology is an imitation of a substantially different technology, this might turn out to be very costly to the firm, which may not have sufficiently trained workers to fully benefit from this new technology.

3 Running the model: Studying the general behaviour of the model

3.1 Variables of interest

Before moving on to adding IPR and other mechanisms to this model, let us first have a look at behaviours exhibited in this model. Although there is a large number of variables to explore, the most interesting effects from a catching up perspective can be observed by playing with a small set of parameters. Mainly here we will be looking at the extent of the northern firms' presence in the local industry, primarily seen through the number of firms present and the size of their advantage (starting capital and equity). The other important variable to consider here is the size of the gap, which shows how far behind the local industry is compared to the foreign competitor. We will also consider the flexibility of the labour market to see if it plays a role in facilitating (or hindering) technological transfers.

Since we set the premise of this model in a country where the presence of foreign - and more technologically advanced - firms are present, we will first be looking into how their presence can affect the local industry. As we have seen, the presence of foreign firms can have both positive and negative outcomes. The benefits may include technological transfers (in the form of imitation and labour training) or higher wages creating more favourable market conditions. The drawbacks however can be seen on the supply or production side where southern firms are not able to compete with the higher productivities, hence a crowding out of the market by northern firms flooding it with their product. A similar crowding effect could potentially exist on the labour market side, where northern firms might be in a better position to attract the better skilled workers, thus limiting the progress of southern firms. This leads us to a first theme to explore: what is the optimal northern presence in the industry for the development of local firms? We can also hypothesise that due to the competitive nature of this industry, what is best for southern firms may be in

contradiction with whatever situation that is more favourable to northern firms. That is we should be looking at what is best for the local industry in terms of size of the northern firms, and see if this setting make for an attractive industry for northern firms. Since in this model there is no entry or exit firms, whether local or foreign, looking at the outcomes of different situations for northern firms may be interesting for policy making. For example, if we see a a particular setting (determined by size of the gap, labour market conditions and size of the northern presence) where northern firms perform rather poorly despite the local firms thriving, this could help us conclude that this situation will be unattractive for foreign firms and thus such a scenario for the development of southern firm would be unrealistic. It is in this regard that success of northern firms is important to consider in this model. To study these effects, we will vary the number of northern firms in the industry and their relative advantage in starting capital and equity.

It was seen also (Crespo and Fontoura (2007)) that the extent of development of a country may also be an important factor in determining the success of the technological catching up and the efficiency of technological transfers to the local firms. For this purpose we will also observe if and how catching-up varies with the size of the gap. In the model, the technological gap is measured in three ways: the number of transitional technological trajectories between the one used by northern firms and the one used by southern firms, the distance between each transitional trajectories and if firms happen to be on the same trajectory, the distance between technologies (θ). In order to study the impact of the technological gap, we here choose to keep constant the distance between trajectories, and change the number of transitional trajectories between the two main ones. Effectively, this change will also affect the distance between the main trajectories. Our expectations regarding the main effect are multiple: with a larger gap, the northern firms have an advantage in terms of productivities, but this also might come with higher costs associated with higher wages. Furthermore, if the local industry is more numerous than the foreign firms, the lower wages paid by the southern firms may not be sufficient to afford the higher priced northern goods which would not bode too well for the foreign firms. This will depend on the average cost of the northern firms.

A third aspect of this model that pertains more to the design of the model itself. We have seen in the first chapter that imitation is necessary for the catching up process will also be studied. We will thus be looking at the role of imitation in the technological

development process.

3.2 Simulation Protocol

3.2.1 Presenting the model interface

The model was programmed using NetLogo 6.0.1, a commonly used software to create agent-based models and run simulations. The file and code are available upon request.

Through the interface we can specify different values for each variable in the model and then observe the behaviour of the model by looking at the evolution of different measures.

A sample configuration of the model was run and is commented in appendix 1 to illustrate what happens to this particular country during, and at the end, of 1000 periods.

Though variables may be changed manually to test different combinations, the complete experiment as described in section 3.2.2 has been programmed in the "Behaviour Space" of NetLogo. The analysis of the results through the use of boxplots, violin plots and regression trees has then been conducted in R version 3.3.

3.2.2 Designing the Monte-Carlo experiment

For these runs of the model, we chose to vary a limited number of variables to focus on the general behaviour of the model. The treatment variables are presented in table 2.1, as well as the name of the variable as used in the figures and the NetLogo interface. We chose to study the impact of the proportion of the presence of the northern firms in the local industry, this is captured by the number of northern firms as well as the size of their advantage.

The technological gap is also a variable of interest. We note that this gap is measured by the number of transitional trajectories between the northern and the southern trajectory. The same difference in productivities can be found from one trajectory on to the next. Therefore the more transitional trajectories, the higher the gap. The reference trajectory is the southern one. This means that as the gap increases, the technological frontier is further away¹³. This has two implications: first, this means that the higher the technological gap, the higher the potential maximum productivity reachable in the industry. This means that if the South managed to catch up every time and the effective productivity of firms followed

¹³An alternative way to look at the problem could have been to fix the frontier for every run and lower the starting southern productivity depending on the gap.

suit, then for a high starting gap, we should observe higher productivities among the local firms. The second implication is that the North does not start always with the same level of productivity depending on the starting gap. A low gap means that northern firms start with a low productivity compared to the case of a higher gap, where the starting productivity of northern firms would be much higher. This can have consequences on the costs for the firms in terms of wages and thus this could affect the performance of northern firms at the start and thus influence the course of the simulation and the final results.

Since the transfers of technology here are highly dependent on the labour force, the shape of the labour market is studied. Mainly we turn our interest to the flexibility of the labour market as captured by the contract length. While workers are not expected to work for the same firm until the legal end of the contract, it would be interesting to see what is the impact of this parameter on firm performance and technological advancement.

Finally, the last variable is the educational gap. This serves as an indicator of internal inequalities. While it may appear to be a weak measure, it leaves the door open for the study of the impact of inner inequalities on catching up. The gap in education affects the starting skills of workers as well as their learning speed, which may affect effective firm productivity in the end.

The parameters that are fixed, as well as their values are specified in the appendix.

Variables	Name	Range	Increments
Number of Northern firms	<i>nbnorthfirms</i>	[2;19]	1
Technological Gap	<i>gap</i>	[0;8]	1
Contract Length	<i>contractlength</i>	[20;300]	20
North Starting Equity	<i>northequity</i>	[10;40]	10
North Starting Capital	<i>northcapital</i>	[0;5]	1
Educational Gap	<i>epsilon</i>	[0;40]	10

Table 3.2: *Treatment variables*

The Monte-Carlo procedure consists first in randomly selecting the values of these variables of interest and then running the model. Each run consists in 1000 periods (called "ticks" in NetLogo language). We run 2000 times the model and record the results of different variables every 100 periods. The next section thus presents the results of this model. We mainly focus on observing the behaviours of the base model.

3.3 Results

The analysis considers the general behaviour of the model given the different treatment variables which values were randomly selected in the Monte-Carlo procedure. Considering the large number of components of the model and their complex interactions, the scope of study for the basic version of the model is quite large. In order to guide our study, we will focus on three main questions.

1. To what extent do southern firms benefit from the northern presence?
2. What are the conditions that facilitate the development of the emerging country?
3. What type of southern country is attractive to northern firms?

Since we hypothesise that southern firms benefit to some extent from the presence of northern firms, studying the conditions that make the country attractive to FDI is important for policy making, notably in shaping the FDI policy of developing countries wishing to benefit from technological transfers through this channel.

Although we focus our study on the effects of FDIs on the local industry, we consider the case where there are no northern firms. This configuration is analysed in the appendix (section 3), and may be used as a benchmark.

Without the north presence, technological mutations are scarce if not inexistent, therefore the industry remains on the first trajectory regardless of the size of the gap. The observations obtained are helpful to study the performance of the industry without technological transfers from the north. In order to answer the above questions, we will be looking at the following aspects. We start by considering the overall performance of the country by looking at economic growth. Then we investigate under what conditions does the country manages to catch up. We thus switch our focus to firm and industry performance, as well as market structure. The analysis will thus allow us to check answers given by the base model to our main questions.

3.3.1 Economic Development

3.3.1.1 Economic Growth First and foremost, we have to look into whether or not the model manages to produce economic growth in any setting. Figure 3.3 shows box plots of the growth rate over time. The growth rate corresponds to the growth in 100 periods.

Due to the fact that we start at period 0 with no production, the growth rate can only be computed from the 200th period.

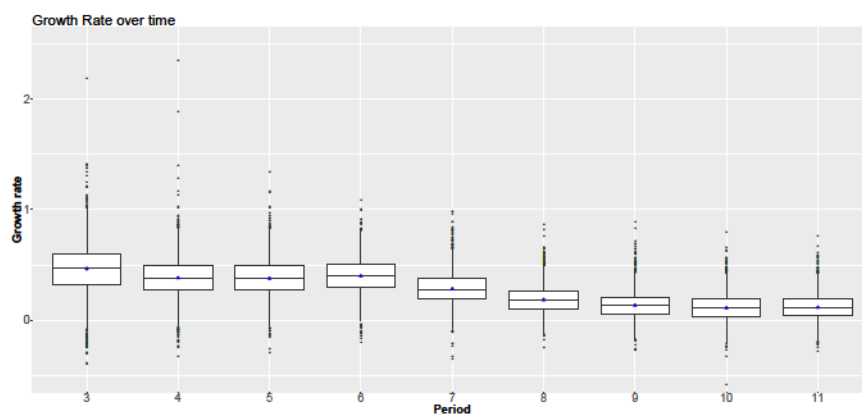


Figure 3.3: *Box plots of the growth rate over time*

Though we do observe some occurrences when the growth rate is negative, the general trend (looking at both median and means) has economic growth remaining positive. Additionally, an interesting result is that the growth rate seems to be decreasing over time. This is concurrent with common results in growth and development economics, with the growth rate decreasing as the country catches up. There is also quite a dispersion in growth rates recorded per period. This variance suggests that the outcome is not certain, and thus it is worth investigating why the economy performs differently conditioned which variables. This will be the topic of the analysis ahead. Figure 3.4 considers the different average growth rate over 1000 periods according to the starting technological gap. Unlike what beta convergence types of studies would suggest, it would seem here that there is a downwards trend of the average growth rate as the gap increases. The variance also increases, thus suggesting that the outcome is all the more uncertain in the case of a large gap. This means that despite the large opportunities to learn and grow, the country does not seem to always be able to exploit those. Instead smaller gaps ensure a more consistent and higher growth.

Proposition 3.6. *A high starting technological gap can hinder the growth of the country.*

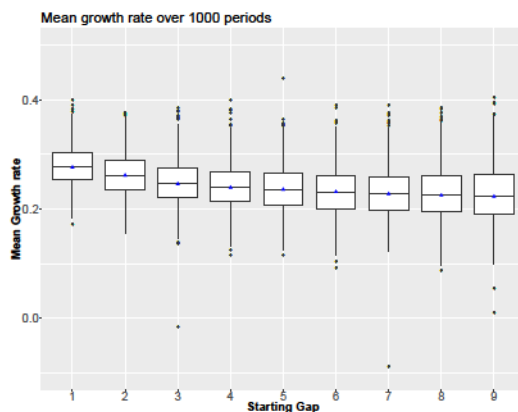


Figure 3.4: *Box plots showing the mean growth rates over 1000 periods according to the initial technological gap*

There is another point to consider regarding this result. A large gap means that the northern firms bring in vastly superior technologies. The fact that the country does not necessarily progress means that those foreign firms are not able to exploit their technological advantage to grow while at the same time the southern firms are not able to learn from the northern firms, which affects the actual growth rate of the country. This is all the more true as we look at figure 3.5(a), which presents the average growth rates according to the number of firms but only considering countries with a large (above 5) technological gap. It shows clearly that a large number of northern firms drives down the growth rate. This negative effect is also present in the case of low gap as shown figure 3.5(b).

Proposition 3.7. *A large presence of northern firms can slow down the growth of the economy regardless of the gap.*

The next sections will attempt to provide a closer look at the different dynamics within the model that may lead to this result. These two propositions do not herald a positive impact of northern firms. However if we consider other metrics, such as the ability for the South to catch up as we do next, we will argue that there is more nuance to the role of northern firms.

3.3.1.2 Catching-up analysis Beyond economic growth, the main objective here is to study the ability a country has to catch up. In the runs without the northern firms (see appendix), we find that no country managed to catch up (they failed to reach the technological frontier due to the lack of transfers, as their innovations were not sufficient attain that level). When we introduce northern FDI, the technological transfers seem to

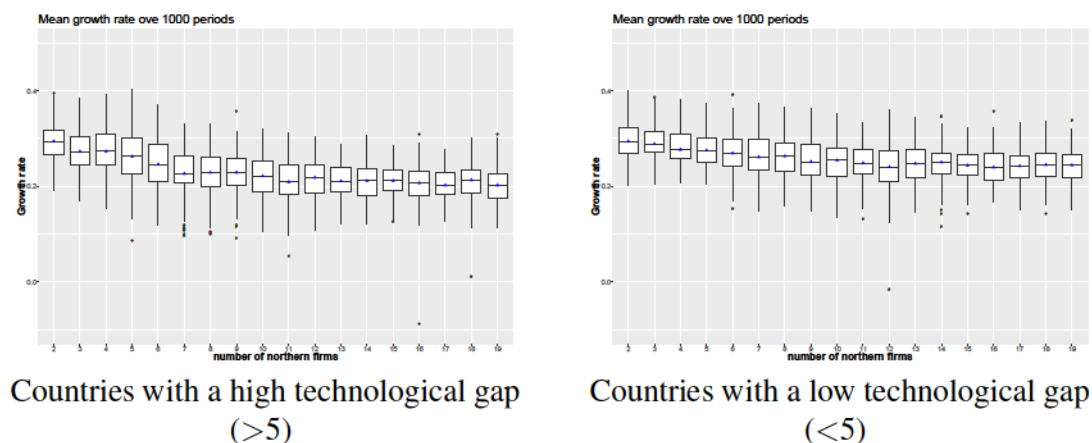


Figure 3.5: *Variation of the mean growth rate according to the number of northern firms*

work as we find in that in 47.5% of cases the South managed to reach the technological trajectory of the North, thus suggesting that they are catching up. This statistic however does not account for the performance of southern firms, this will be discussed further. For now we look at what can facilitate technological catching up. In order to do that, we generate a dummy variable that takes the value 1 if during a run at least one local firm has managed to reach the technological trajectory of the North, and 0 otherwise. This would mean that technological catching up succeeded, though this does not necessarily imply that the whole industry is technologically and economically successful. With this dummy variable, we run a Logit regression in order to determine what factors may influence the probability of succeeding in catching up. The dependent variable is thus the binary variable "successcatchup" and we include in the model the following variables: the number of northern firms, its square to test for quadratic effects, the educational gap (epsilon), the size of the gap and its square, the shape of the labour market through the contract length and the number of imitations and innovations made by southern firms (adjusted for the number of southern firms in the industry). The model thus estimated using maximum likelihood is :

$$\begin{aligned}
 success = & \beta_0 + \beta_1 nbnorthfirms + \beta_2 nbnorthfirms^2 + \beta_3 epsilon + \beta_4 Gap + \beta_5 Gap^2 \\
 & + \beta_6 contractlength + \beta_7 innovations_{south} + \beta_8 imitations_{south}
 \end{aligned}$$

The number of innovations and imitations achieved in the run happens to be correlated (table 3.3) to the other variables (chiefly the number of firms and the gap) as they are the

result of the technological development influenced by the state of the country. Although they are correlated, they are not solely determined by these variables and thus explain an effect that is not captured by those two other variables.

	nbnorthfirms	nbnorthfirmssq	epsilon	gap	gapsq	contractlength	south_innovations_adj	south_imitations_adj
nbnorthfirms	1.00							
nbnorthfirmssq	0.98****	1.00						
epsilon	0.01	0.01	1.00					
gap	-0.01	-0.01	-0.02	1.00				
gapsq	-0.01	-0.01	-0.02	0.96****	1.00			
contractlength	0.00	0.00	-0.02	0.03	0.03	1.00		
south_innovations_adj	-0.58****	-0.58****	0.04	-0.07**	-0.05*	0.43****	1.00	
south_imitations_adj	-0.49****	-0.46****	0.07**	-0.35****	-0.23****	0.31****	0.59****	1.00

Table 3.3: *correlation coefficient table of the explanatory variables*

Their inclusion did not however modified the general results of the model, and they turned out to be significant. Other specifications were tested but to keep the focus on the results, we chose not to include them.

	<i>Dependent variable:</i>		
	Logit	Odds Ratio	Marginal effect
nbnorthfirms	0.484*** (0.077)	1.623***	0.117***
nbnorthfirmssq	-0.021*** (0.003)	0.979***	-0.005***
epsilon	-0.008 (0.005)	0.992	-0.002
gap	-1.596*** (0.158)	0.202***	-0.385***
gapsq	0.131*** (0.016)	1.139***	0.031***
contractlength	-0.003*** (0.001)	0.997***	-0.001***
south_innovations_adj	0.019*** (0.001)	1.019***	0.004***
south_imitations_adj	0.093*** (0.019)	1.098***	0.022***
Constant	-3.557*** (0.572)		

*p<0.1; **p<0.05; ***p<0.01

Table 3.4: *Probability of catching up: Logit regression output*

Table 3.4 presents the result of the regression as well as the computed odds ratio and marginal effect. We use those latter two to interpret the coefficients from this logit

estimation. The odds ratio is interpreted by saying, for example in the case of the number of northern firms that a country is 1.6 more likely to succeed in catching up if it adds one northern firm. The marginal effect for this variable is 0.117, which means that increasing the number of northern firms by one increase the probability of success by 11.7%.

Here according to the results of the regression it seems that the number of northern firms affects positively the chances of successfully catching up. There is however a significant negative quadratic effect. This means that while the increasing presence of northern firms facilitate catching up by providing a larger source for technological transfers, too many firms can also hinder the catching up process by killing the local industry (see also section 3.3.2.3). The starting technological gap has a negative effect though once again there seems to be a significant quadratic effect. It seems that increasing the gap reduce the probability of successfully catching up by 38.5%. This makes more sense when reading the result in the other direction, a smaller gap makes it more likely to catch up since the southern firms are more relatively competitive with their northern counterpart. The quadratic effect likely translates a risk that when the southern firms are too close to the northern firms in terms of productivity, the competition is more intense. Inversely, firms dealing with higher gaps are also firms with comparatively lower wages, which reduces their production costs. In such environments, the southern firms are more likely to survive and develop until they are able to catch up.

Though the contract length coefficient seems low (still significant though), it should be noted that contract lengths increase in 20 units, thus making the impact of those coefficients greater. It would appear that the more flexible the labour market, the more likely the industry is to catch up. While this may be explained by the fact that labour turnover is higher, thus in theory facilitating transfers, there are more complexities to the effect of the labour market than this first result seem to suggest. This will be discussed closer in section 3.3.4.1.

Finally both innovation and imitation play a significantly expected positive effect. The only way for technology to advance is through those means. Increasing the quantity of each increases the opportunity for firms to learn new technologies, including technologies that will lead them to the northern technology. These first observations formulate the first proposition

Proposition 3.8. *Technological catching up is facilitated by increasing opportunities for*

technological transfers to the extent that the competitive environment is not too intense.

For the countries that do succeed in catching up, we can look at what affects the speed of catching up. We consider the subsample of firms that did manage to catch up and run OLS regressions on similar explanatory variables as in the logit regression. The explained variable is the period at which the first southern firm has reached the northern trajectory. Once again, this does not necessarily imply that the firm in question manages to survive or even outperform the northern firm. Multiple configurations were tested, a select few are presented in the appendix (Table F.2). We would retain the first estimated model. It seems that the same variables that affect the likelihood of catching up affect the speed of catching up with the exception of contract length. This means that while the flexibility of the labour market increases the chances of catching up, it does not speed it up, or at least not significantly so. Innovations slows the process whereas imitation speeds it up. Keeping in mind that all runs in this case have managed to catch up, it does not mean that innovations hinders the possibilities for catching up, since we saw previously that it increased the probability of successfully doing so. It does mean however that technological development based on imitation will be faster than a development relying on solely innovation. This is coherent with the observations regarding the case with no northern firms, where the industry failed to reach the technological frontier at the end of 1000 periods, even though innovations were happening. It also echoes a result found in the first chapter that lead to a conclusion that imitation was necessary to allow countries to catch up,

Proposition 3.9. *The local industry cannot rely solely on their own innovations to effectively progress. Technological transfers by way of imitation greatly facilitates the catching up process by speeding it up.*

The speed of catching up is also important considering that an effect not presented here is the development of the North beyond their trajectory. If the North continues to advance as the South takes too long to progress, the catching up process may be hindered.

In the case where the South manages to catch up to the North, we now look the overall performance of the southern industry in comparison to the northern industry. Mainly this serves to answer the question of what happens once the South joined the northern trajectory and if they manage to be sufficiently competitive. We look at the 47.5% of industries that did manage to catch up. Of those industries:

- 20.7% manage to end up with higher mean effective productivity than the North. A result that is all the more interesting as only 15.6% of those cases had a technology that is farther on the trajectory than that of the North. This means that those southern firms manage to recruit better workers than the North overall.
- 66.6% where observing higher average profits than the northern firms.
- 2.2% saw the northern firms stopping activity and 2% of cases saw the southern firms stopping their activities.

Those statistics tell us that in general when the southern industry manages to catch up with the North, southern firms survive and are able to find ways to do so even while outperforming their northern counterparts. In the cases where the southern firms failed to catch up with the North, 57.3% of those cases saw the southern firms stopping activities. This means that if catching up fails, there is a 57.3% chance that the southern firms in the industry will not survive.

It thus seems that the North plays an important role in facilitating catching up and technological development. The fact that economic growth seems negatively affected by the northern firms suggests that this comes from a potential negative effect on industry performance despite a positive effect on technology. The next sections focus on bringing to light this duality between industry performance and technological progress.

3.3.2 Industry performance and market structure

In light of our previous observations, the next focus turns to industry and firm performance. We saw generalities regarding the overall performances with regards to catching up. We will now be looking at what happens specifically to firms inside the industry and how the market is affected by different parameters.

3.3.2.1 Effective Productivity We start by looking at effective productivity. The violin plots we use in this analysis represent the spread of observations, the median is represented by a blue triangle while the mean is represented by a red dot. The advantage of the violin plots is that in some cases they show more information than box plots by displaying the distribution at each value. Figure 3.6 shows how the mean effective productivity of the southern firms compares to that of northern firms at the end of the 1000 period run for

different values of the gap. Figure 3.7 shows the same information but for the industry as whole, whereas figure 3.8 focuses on the productivity differential. Figures F.5, F.6, F.7 and F.8 in the appendix show respectively the same information but according to the number of northern firms at the start of the run.

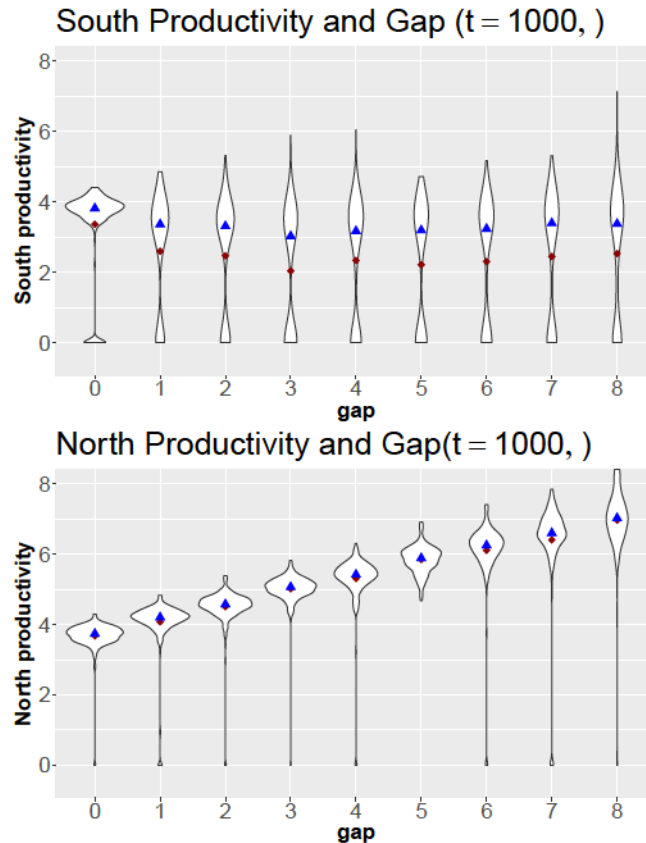


Figure 3.6: *Mean effective productivity according to the initial technological gap: South vs North*

We can see that for the South if there is no gap¹⁴, the effective productivity observed is higher than if there is a gap of at least 1. Furthermore with no gap, the results are quite consistent, whereas in all other cases they are quite spread out. If we look at the northern firms, the effective productivity seems to be more consistently distributed, regardless of the gap. Unlike for southern firms however, a higher gap leads to higher productivity. This is normal because a higher gap only pushes the technological frontier upwards,

¹⁴No gap still means there are two distinct North and South trajectories, just that there is no transitional trajectory between the two; the next radical innovation from the southern firms bring them directly to the northern trajectory.

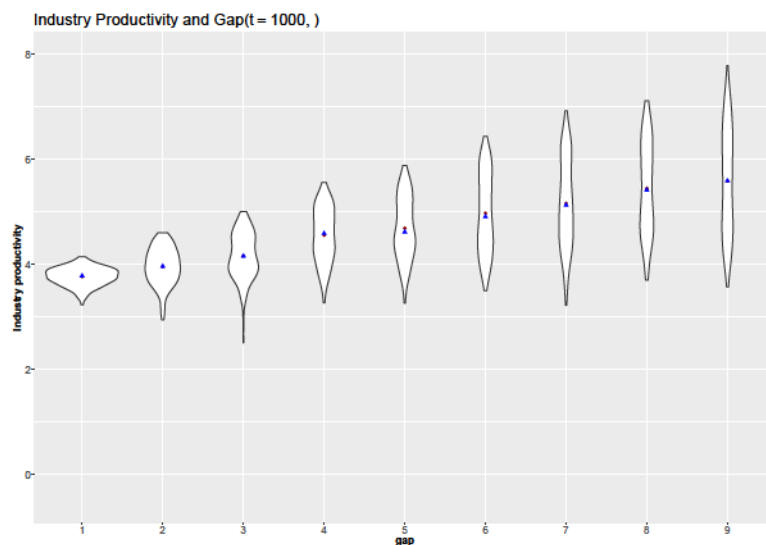


Figure 3.7: *Mean effective productivity in the industry according to the initial technological gap*

giving northern firms naturally higher productivities. This contrasts with what is found for southern firms, as their effective productivity remains unaffected by the gap, thus suggesting that there is not that much progression happening. Looking at the overall industrial level, we find that the average productivity increases with the gap. Given our previous observations it would seem that this increase is solely driven by the northern firms. Regarding the productivity differential, there seems to be a very light downwards trend, which mirrors those previous results. The case of zero gap however seems to suggest that the median is slightly above 1, thus meaning that southern firms are outperforming northern firms when the gap is almost inexistent. This would suggest that in an environment where southern firms are close to northern firms, southern firms will in general end up by out performing northern firms. This is likely because in such cases with high proximity between North and South, southern firms are more competitive and benefit fully from spillovers, in the sense that they not experience an initial setback in performance.

We can compare these results with the productivity levels obtained according to the number of northern firms in the industry (figure E.5). For northern firms, if there are more than 5 northern firms in the industry, their performance in terms of productivity does not seem to be affected by the number of northern competitors. If there are less than five firms however the productivity decreases as the number of northern firms decreases, thus suggesting that a large number majority of southern firms affect negatively the performances of northern firms. This result is apparent in the southern firms productivity

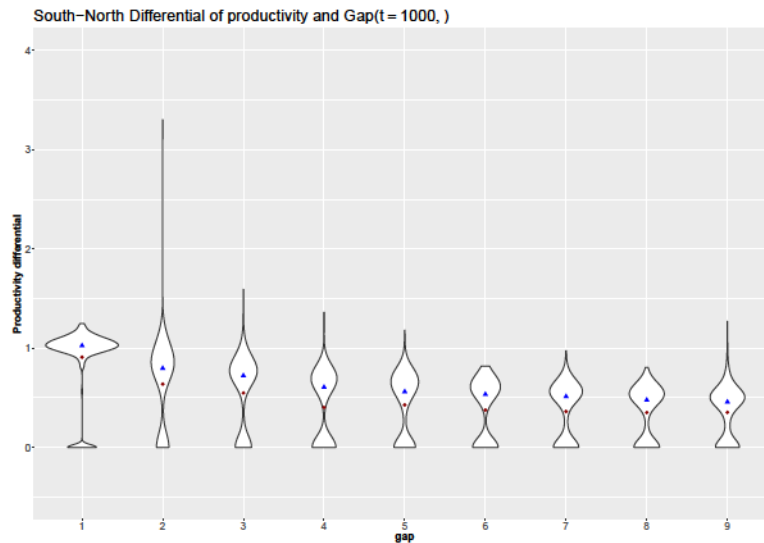


Figure 3.8: *South-North productivity differential according to the gap*

output: with up to 5 northern firms in the industry the productivity of southern firms stays consistent and high. they then start decreasing, with results being spread out. With 14 northern firms in the industry the median effective productivity falls to 0 (meaning the southern firms cease their activity). At 15 northern firms, the results do not change much either, though this observation is interesting from statistical point of view as it illustrates why violin plots are more useful than box plots in this case. While the median seems largely superior to that of the cases with 14 and 16 northern firms, the distribution similar, exhibiting highly heterogenous results among runs with the name number of northern firms. This means in this case that the mean and median would yield a wrong interpretation.

These results are highly heterogenous, meaning that there are more variables in play that influence the performance of northern and southern firms. To have a more comprehensive look at the role of different variables, we compute regression trees. Regression trees show how different chosen explanatory variables affect a given dependent variable. In this case we will be testing separately the variables affecting southern effective productivity, and northern effective productivity. The explanatory variables will be the treatment variables of the simulations. Figure 3.9 shows the trees for the effective productivity of southern and northern firms. All results displayed on the trees are 99% significant.

In order to read the tree we shall take the example of the rightmost branch of figure 3.9. At the bottom of the branch, the leaf reads 3.78. The leftmost branch shows the cases with lowest productivity whereas the rightmost branch shows the cases highest productivity recorded. Here that averages 3.78. We then read the branches that lead to that leaf, here it

says "nbnorthfirms < 10.5" followed by "contract length ">= 150". We interpret this by saying that if there are less than 10.5 firms, and a labour market somewhat less flexible (contract length above 150), then in those cases the productivity of the southern firms will be less. Conversely for the case of low productivities, it would seem that a high number of firms, accompanied by a somewhat flexible labour market and a non zero gap will lead to low performances. Another example would be looking at leaves 7 (productivity = 0.95) and 8 (productivity = 2.72). These two leaves show the same configurations of northern firms (a number between 10.5 and 7.5), contract length (less than 150, so a flexible labour market), gap (greater than 2.5). However at the last branches the difference is made on northern equity. However, if the northern firms in that exact configuration start with less than 15 supplementary equity than southern firms, then the overall average productivity is multiplied by 3. Northern equity is not always significant, but in that particular case it does make a difference. Those observations allow us to understand given the complexity of the model, some variables may play a more subtle role than it appears. These observations on effective productivity bring the following propositions :

Proposition 3.10. *While they cannot progress technologically without the help of northern firms, southern firms will not thrive in an environment with too many foreign firms with a high technological advantage.*

This proposition is based on observations made on the effective productivity alone. We turn to studying production and profits to see if the link between productivity and profitability is substantiated.

3.3.2.2 Profitability and investment Figure F.9 in the appendix plots the mean effective productivity of northern and southern firms separately against the mean and max profits. We see that at first look there is no evidence of a clear link between the productivity of each segment of the industry and the profits recorded. Profits are the results of sales (affected by prices) to which we removed the total costs (modulated by the wages). With a high productivity, even if the production is high, it does not necessarily mean that there will be sales. While there does not seem to be a link between effective productivity and profitability, there appears a clear positive relationship between profits and capital (figure 3.10).

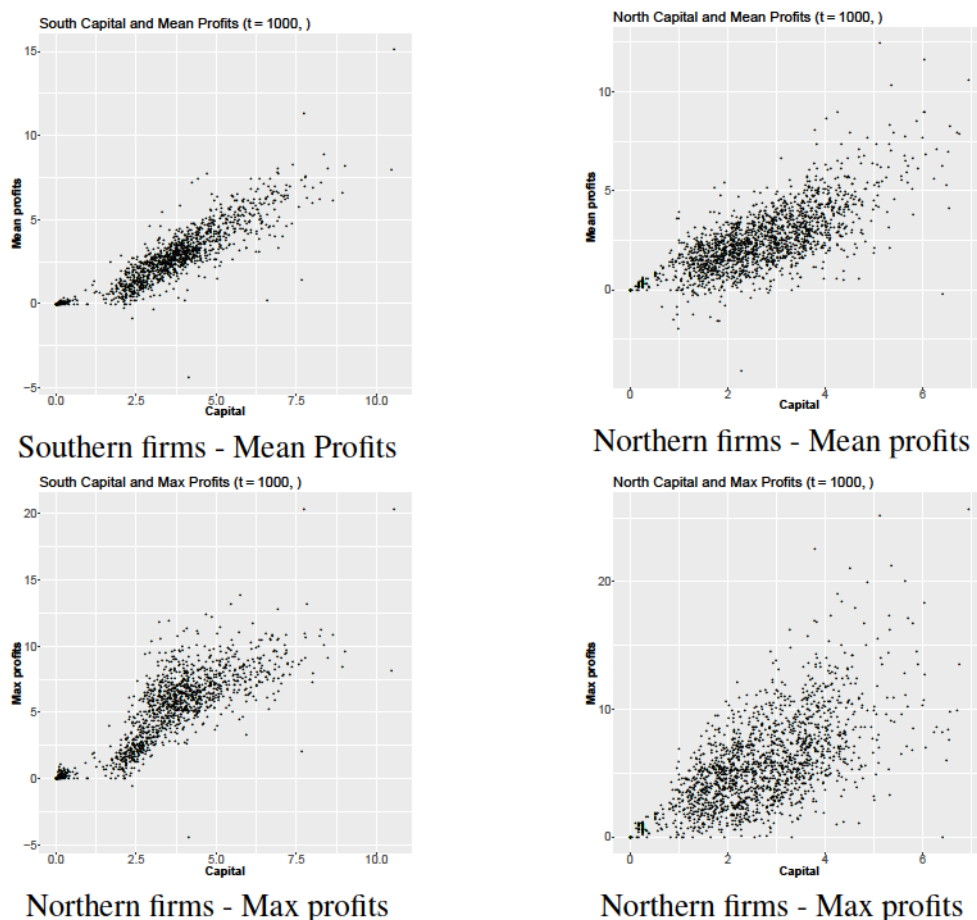


Figure 3.10: Scatter plots showing the relationship between profits and capital at the 1000 period

The causality relationship may be questioned: is it profits that enable high capital investments or is it the high capital investment that allow for higher profits? We would argue that since the data considered here is the data at the end of the period, profits are facilitated by the scale of firms, otherwise the industry would not have been able to bear the costs associated with high capital and stopped investing to reduce costs and make more profits. This relationship appears to remain true whichever the period retained (see figure F.10 in the appendix). It would also appear that this positive effects comes from the fact that with higher capital (figure 3.11), we tend to observe higher sales. Since the same cannot be said about productivity and sales (figure F.11), it would appear that the size of the firm impacts profitability more than productivity itself.

Proposition 3.11. *The profitability in the industry is positively correlated with the level capital.*

This goes in the direction that the growth rate is driven by production.

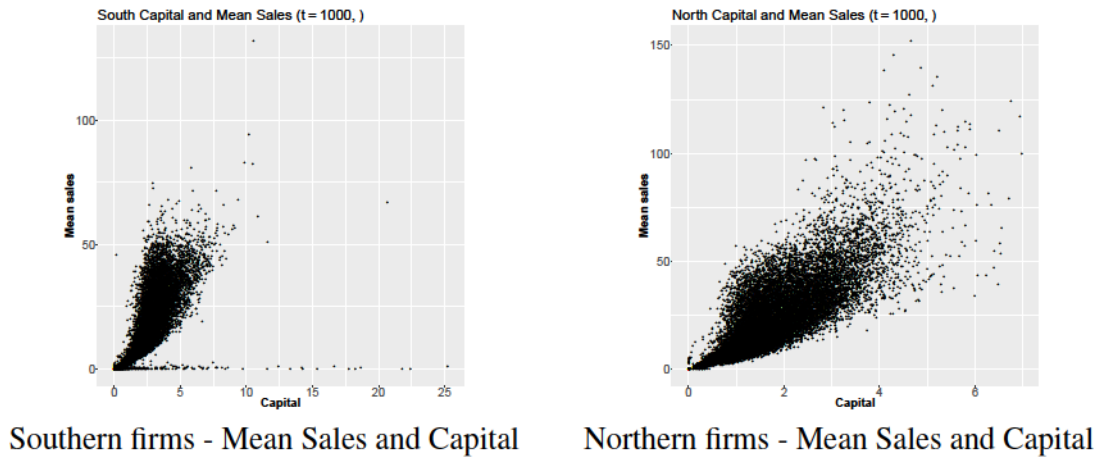


Figure 3.11: *Scatter plots showing the relationship between sales and capital at period 1000*

Given the model's design there should be a positive relationship between capital investment and productivity (see section 3 in the appendix, shown on figure F.12). The results we have so far do not attribute a significant positive relationship between effective productivity and the size of the firm or profitability. The size of the firm and its relation with profits is a self-reinforced mechanism. Therefore, if we were to study which variables affect the profitability through a regression tree, we cannot include capital as an explanatory variable. We thus try to have a closer look at the relationship between productivity and profit, by controlling for the usual treatment variables. Figure 3.12 shows the corresponding regression tree for the southern firms. The explanatory variables are the experiment parameters (which we use as control variables) with the addition of the average effective productivity among southern firms. We note the effective productivity for southern firms is not correlated with the gap as we have seen previously, therefore there is no endogeneity problem here. It shows that the productivity of the southern firms affects positively profits, under certain conditions. Consistently however, if the average productivity is above the threshold 2.22, profits will be higher. We note that under the parameter of the model 2.22 is not necessarily synonymous with high technological progress, especially at the end of the period since the starting southern productivity is 2, and the northern productivity starts at 2.5. Therefore while effective productivity matters, we do not see a significant difference in profits when the southern firms do manage to reach higher levels of productivity. The number of northern firms must be high. Figure F.13 in the appendix shows the violin plot of southern profits against the number of northern firms, it shows a high variance in profits

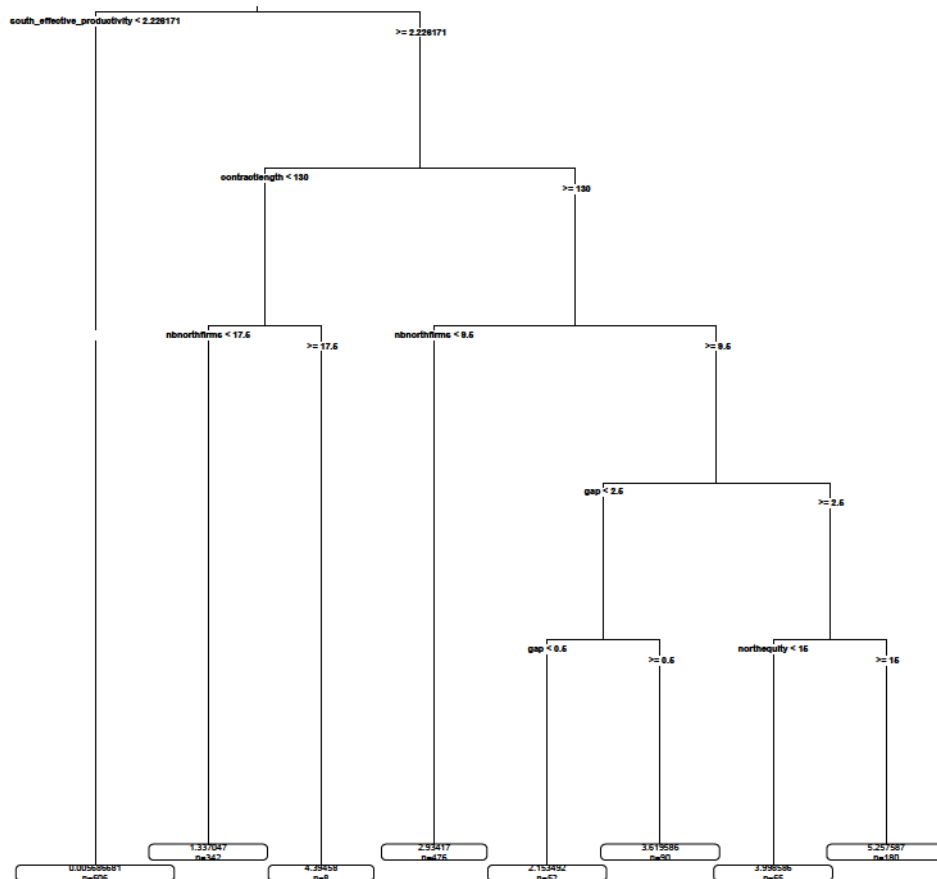


Figure 3.12: *Regression tree showing the impact of productivity on profits of the South*

according to the number of northern firms, (except with 19 firms, which seems to kill the southern part of the industry), which means that while this factor counts, it does not work by itself. Other variables affecting profits are the labour market flexibility. If there are many northern firms, then contracts must be long to ensure higher profits. The gap also seems to affect results. Particularly, in the absence of a gap, there is a competition effect that drives profits down (also seen on figure F.14 in the appendix.)

We have solely been looking at the average of southern firms. Technological transfers and catching up however are measured by when does the first southern firm receive the northern technology. This implies that the entirety of the southern firms may not benefit from those technological transfers, it is possible that a select few do. We then look at how the market is structured and investigate top performers instead of the average performance. This will also tell us if the benefits from technological transfers can only concern a select few.

3.3.2.3 Market Structure We saw that larger firms are more profitable. A question to ask here is if this should lead to emergence of monopolies. That is if there is one large firm, is it going to register higher profits? This is important to consider as we look at the impact of northern firms on the industry. If we have emergence of monopolies, basic economics would associate this with primarily negative outcomes. It risks driving up prices (though that not possible in our model given the design of the price system, it would be translated with more unsatisfied demand) and destroying firms, thus affecting unemployment and wage levels. It would also diminish the impact of technological transfers, since having more firms facilitates those to some extent. A first element that will be useful to understand the structure of the industry is to look at the rate of southern firms survival according to the number of northern firms (figure 3.13), computed by using the ratio of active southern firms at the end of the run to the number of southern firms at the beginning of the run.

While the distribution is quite spread out, the mean and median decreases with the proportion of northern firms in the industry. This suggest that the numerical advantage of northern firms can under certain conditions reinforce the advantages of northern firms. The regression tree on the south survival rate in the appendix (figure F.15), show for example that long contracts play a positive role, the absence of a gap as well. The other advantages of the north such as starting equity or capital do not play a role, thus indicating that the

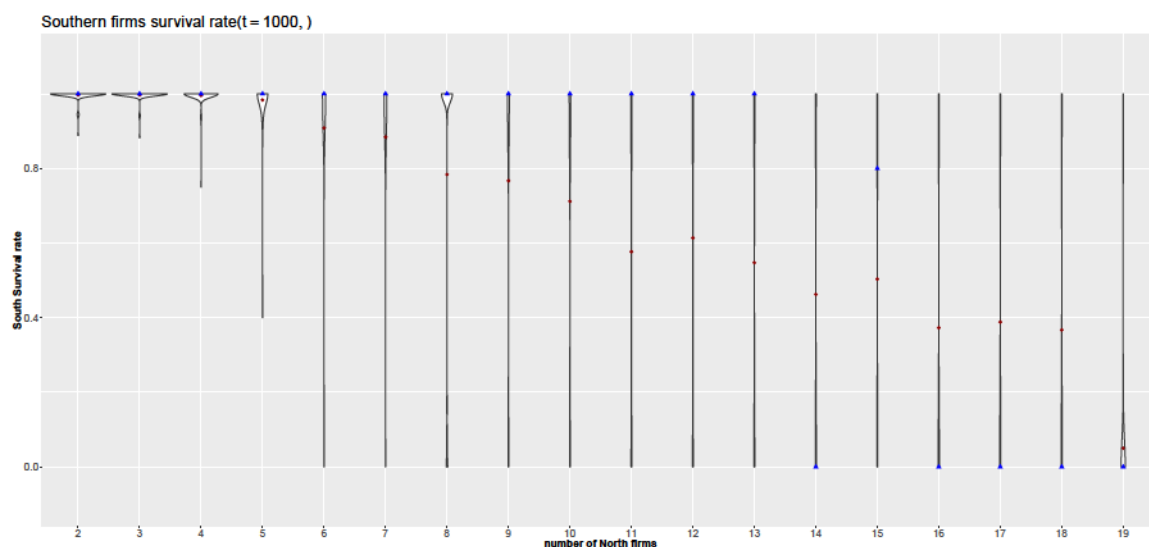


Figure 3.13: *Southern Firms Survival Rate according to the Number of Northern Firms*

competitive edge of northern firms that can drive out southern firms is based on their technological advantage and the numerical superiority.

Proposition 3.12. *As the number of northern firms increase, the chances of survival of southern firms decreases.*

Let us consider the concentration of the industry. There are two metrics used here, first the labour concentration. This variable tells us if the labour force is evenly distributed among a set of firms or not. This is an indicator of size of the firm. If the distribution is not even, this means that some firms hire way more workers (and are thus larger) than their peers. Similarly we consider the concentration of production as a second indicator. These indicators take the value from 0 to 1. It is computed as an inverse Herfindahl index, corrected by the number of firms. If the indicator is closed to 1, this means there is an even distribution of workers or production among the set of firms. If it is close to 0 this means that there exist some firms which are larger or producing more. Given the positive relationship between size of the firm and profit, we would infer that the firms that concentrate more production or workers are top performing firms. However, looking at figures 3.14 it would appear that the highest levels of either capital or profits are recorded when the southern part of the industry is not highly concentrated. This indicates that the southern firms perform better when their local rivals are also performing well. There is no emergence of top performers. A similar result is found for northern firms. Looking at the proportion of surviving firms and maximum capital and profit seems to suggest a similar

result.

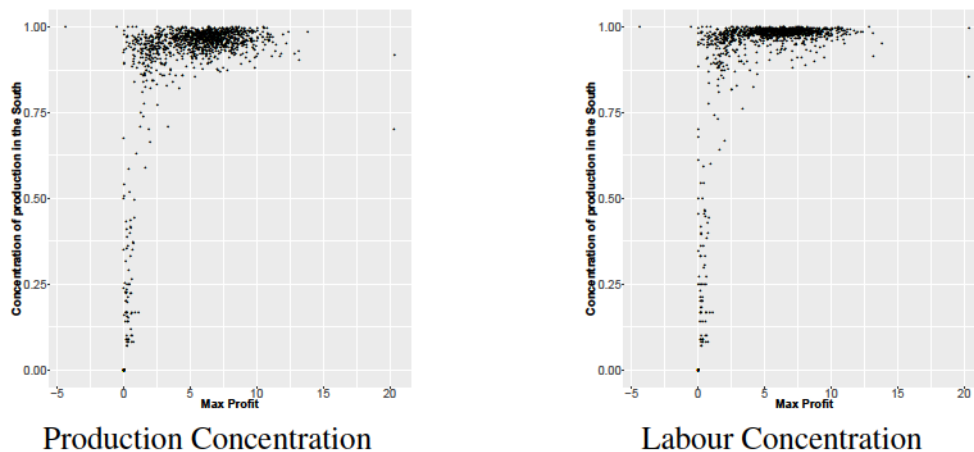


Figure 3.14: *Scatter plots showing the relationship between south firms concentration and the maximum profit reached by a Southern firm (at the 1000th period)*

Proposition 3.13. *Southern firms perform better when their peers are observing similar performances. There is no emergence of top southern firms that monopolise their market.*

The results change when looking at the whole industry (southern and northern firms together). Figure 3.15 plots the max profits reached against labour concentration. It would seem that there are more cases here of industries with high concentration observing higher profits. The blue dots represent the cases where a southern firm has obtained the maximum profit than the north. Apart from a few observations, when industries register high level of profits and are highly concentrated, the north seems to be experiencing the better results, suggesting that if high profits are to be observed in the industry it is likely to be at the expense of southern firms. Northern firms will be in general highly performing, and there might not be a clear northern monopolist. Rather the industry will be led solely by those northern firms.

Proposition 3.14. *If northern firms are making high profits, it is associated with low performing southern industry.*

This is also visible while looking at the survival rate of southern firms and the level of profits registered by northern firms (figure F.16 in the appendix). While there seems to be two cases: either the southern industry fully survives or all southern firms die, the northern firms mean profits are higher when the whole southern industry dies.

These results illustrate why the entrance of northern firms might be dangerous for the southern industry.

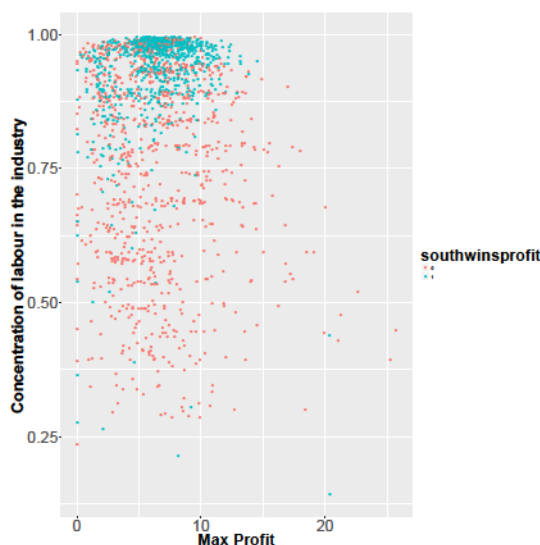


Figure 3.15: *Concentration of labour in the industry and maximum level of profits reached*

3.3.3 Technological development

It is clear from the observations on catching up that the transfers from northern firms are needed for the south to catch up technologically. It is however made at the expense of the southern firms. In this section, we focus on how the technological development is achieved. Since we focus on technological learning, now we consider the potential productivity of firms, as this is the indicator of the technological level of the firms.

3.3.3.1 Factors facilitating innovations and imitations and knowledge growth In order to measure the technological advancement, we consider studying the following variables: the mean knowledge stock of southern firms, the number of imitations and innovations (adjusted for the number of southern firms), and the potential productivity of southern firms all at the end of the run. We first look at regression trees for these four measures with the experiment variables as explanatory variables.

Since there is a strong positive correlation with the mean knowledge and innovations, the trees ended up being very similar. Therefore we report here only the trees for imitation and innovation (figures 3.17 and 3.16). The other two trees are in the appendix (F.18). Looking at the imitation tree it appears that the first factor affecting the number of imitation is the gap. With no gap, imitations are greatly facilitated. The other factors facilitating imitation are a low number of northern competitors, though only in the case with a significant gap. This means that in the case with no gap¹⁵, southern and northern firms

¹⁵No gap here means that there is no transitional trajectory between the North and the South, it only takes

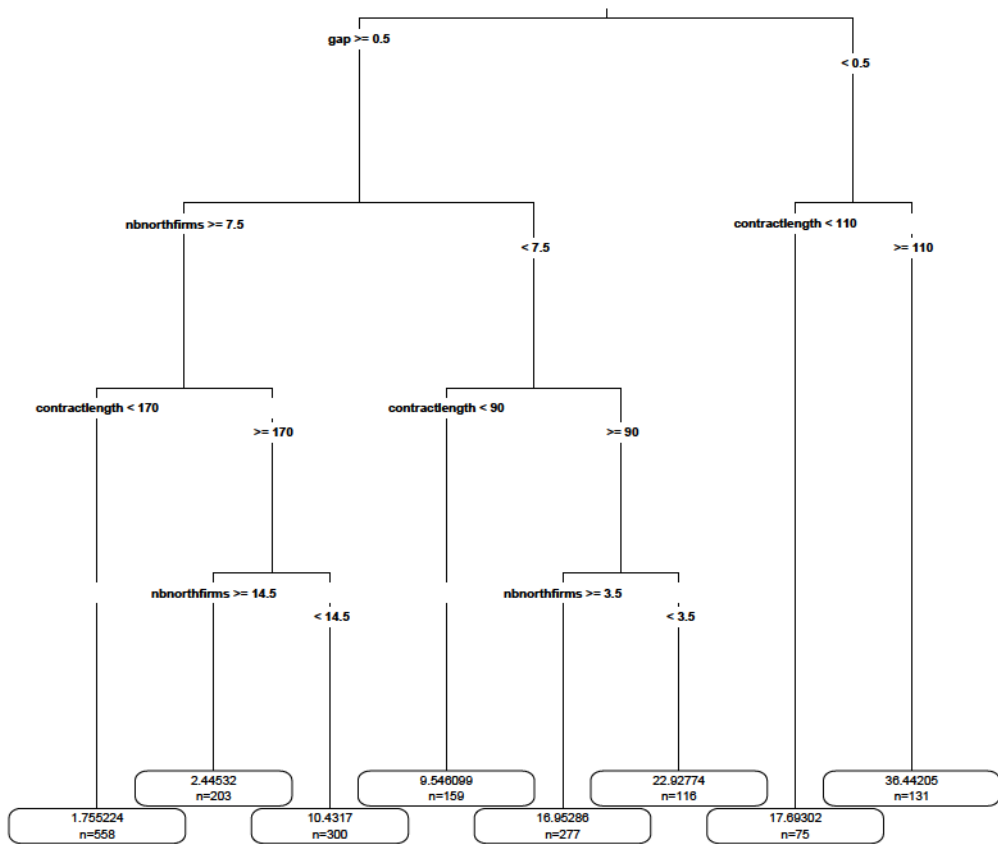


Figure 3.16: *Regression tree for the average number of imitations per firm*

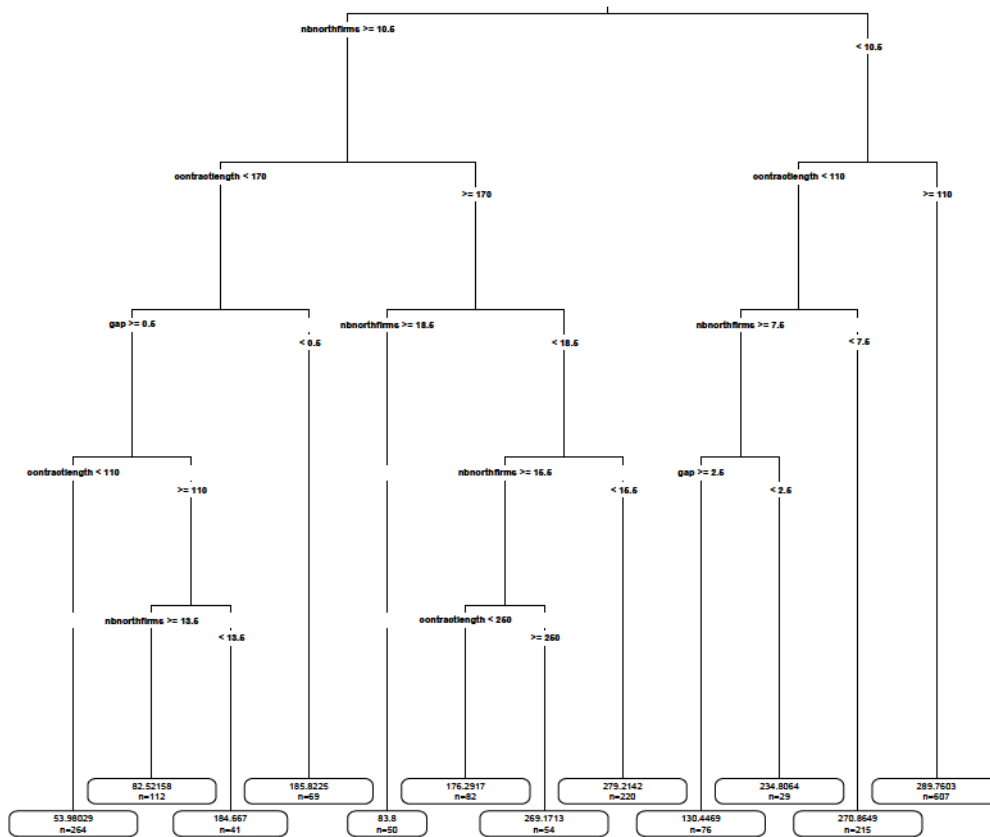


Figure 3.17: *Regression tree for the average number of innovations per firm*

are basically direct competitors, and the northern technology is not difficult to attain for southern firms who can hold their own with or without a numerical advantage. In the presence of a gap however, a low number of northern competitors improves southern firm survival, thus facilitating opportunities for imitation. Longer contracts are also propitious imitations, though this may also be linked to firm survival as we saw earlier.

The innovations are driven by similar factors, with the northern firms playing a more important role. The fact that the same relationship exist between those factors and technological performance and firm performance tells us that logically it is the good firm performance that enables the firms's technological progress, which in turn improves firm performance.

3.3.3.2 The role of imitation in the technological development While imitation is present in the model, we restricted the possibilities for firms to do so by limiting imitation of only currently used technologies (under the assumption that firms may only imitate what they observe, and they cannot observe all their competitors) and if they have employees to orient such imitation. Since the only mode of technological transfers we have here is imitation through the labour force, it is worth having a closer look at the impact of the imitation dynamics on the development of firms.

Due to the mentioned limitation, imitations are less frequent than innovations from southern firms in this model. However, the analysis of catching-up showed that while innovation helps the catching up process, imitation hastens it. Relying on innovation of the South alone does not allow for sufficient technological transfers.

If we look at figure 3.18 we can see that the level of knowledge in the South is positively correlated with the number of both imitations and innovations. However, this relationship is much apparent for innovations than imitations, as imitations seem to have a logarithmic relationship with the mean level of knowledge attained among southern firms. This can be due to a scale effect since there are way less imitations than innovations by design. However it tells us that the level of knowledge is mainly driven by innovation. It could be due to the fact that only a handful of imitations are sufficient to send the technological development on the right path: once the firm copied the latest technology, there is not much more to imitate and the rest of development is up to innovation. With a low gap, one radical innovation to move on to the northern trajectory.

there are more imitations but the knowledge stock does not seem to be much affected. In the case of high gap, imitations contribute more to the knowledge stock, they are however rarer. For innovations, a high number of innovations is necessarily associated with a level of knowledge.

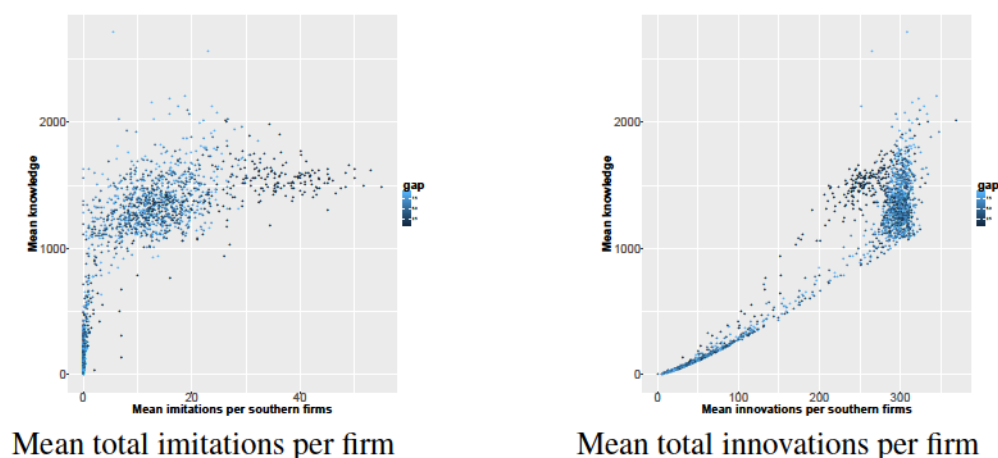


Figure 3.18: *Determinants of knowledge stock for southern firms at the 1000th period*

However, this does not disprove that imitation is not useful. We saw that technological catching up was sped up by imitations. Of the 47.5% observations where at least one southern firm managed to reach the northern technological trajectory, only 26.47% observations saw a sufficient number of radical innovations (transitional innovations) at around the time of catching up¹⁶ to suggest that the technological catching up process might be due to the innovation process. However, only 0.6% of the successfully caught up observations had no imitations, suggesting that at the very least it is possible, though very rare, that catching up can happen through innovation solely¹⁷. While the data does not tell us if for sure the technological catching up is due to innovation or imitation, this statistics tells us for sure that at least 74.53% of the observations where there was technological catch up is due to southern firms imitating the northern firms. This shows that imitation is an important part of the technological catching up process.

Figure 3.19 shows that while when the gap is non-existent only very few imitations are necessary for a southern firm to reach the northern trajectory, this number on average

¹⁶Since the observations are only recorded every 100 periods, there might be some noise in that observation. For example, if catching up happened at the 461 period, we would read that information on the observation for the 500th period. It would be reported that at 500 ticks, x number of radical innovations were observed, while the technological catching up happened at tick 461. There is thus no way to tell if at 461 ticks there were sufficient radical innovations to lead to catching up.

¹⁷This goes with our previous observation that without northern firms to imitate from, technological catching was scarce too.

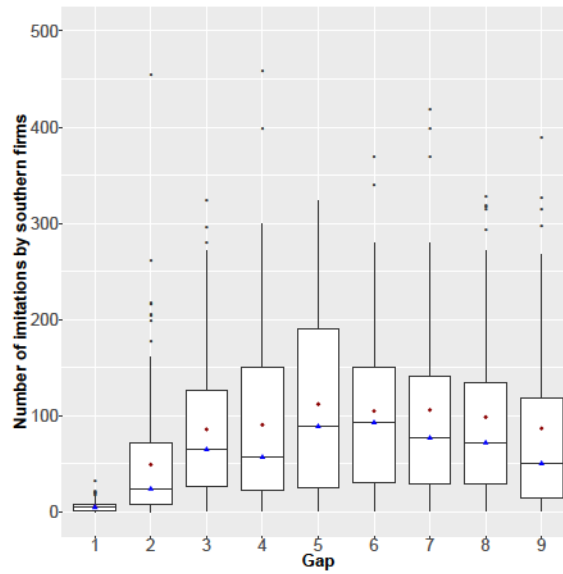


Figure 3.19: *Number of imitations by the South necessary to catch up, by technological gap*

increases as gap increase up until a certain point. Once the gap starts to become large, the average number of imitations needed decreases. We already know that when the gap is large, catching up is less likely to happen, so we can infer from these results that if catching up did happen in the case of the high technological gap, it is mainly by chance.

Proposition 3.15. *While innovation is useful to build up the knowledge base, imitation remains necessary to attain higher technological trajectories.*

3.3.3.3 North to South technological transfers Since imitation is important for the technological development of firms and the catching process, we look at how the labour turnover channel functions here. We computed the average proportion of workers who have worked in the north in the southern firms' labour force. We expect that the more former northern workers working in southern firms, the higher the technological progress for southern firms.

We find on figure 3.20 that there is a positive relationship between this variable and the total number of imitations in the South. No such relationship exists with innovation number. This shows evidence that a high labour turnover from northern firms to southern firms facilitate the imitation, and thus the transfers of technology. We notice on the scatter plot that there is a group of observations on the upper left which corresponds to a low number of northern firms. A low number of northern firms does not mathematically permit a high proportion of northern workers within southern firms. Furthermore, the plot shows

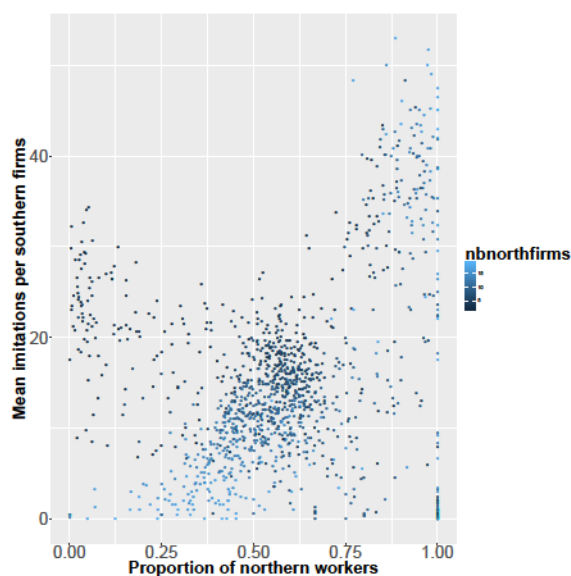


Figure 3.20: *Proportion of northern workers in southern firms and mean number of imitations (1000th period)*

that there is a level effect with the number of northern firms. With the high proportion of northern firms, the proportion of northern workers can either remain low or attain extremely high levels, with the imitations following this. As the number of northern firms decreases, the level of imitations seem to increase, echoing the link between northern firms proportion, firm performance and technological development.

Figure 3.21 shows that over time the proportion of northern workers working for southern firms increases, with a slight downturn at the period 1000. This observation confirms that labour turnover is a lengthy process. Therefore any technological development that would be based on this channel would be a long term process.

The regression tree (for the 1000th period) 3.22 shows if the gap is 0, then provided that there are not a exceedingly large proportion of northern firms that would drive the southern firms out of the industry, the proportion of northern workers in southern firms is high. This is because as southern firms are quite similar to northern firms, it is quite easy for southern firms to recruit northern workers, since they can offer competitive wages (also see next section on the wage differential and gap). In the rest of cases, a low number of northern firms increases the proportion in question, provided the number of northern firms is not too low: if there are less than 2 northern firms in the industry, then the average proportion of northern workers within south firms falls dramatically, even though we saw that with a low number of northern firms, southern firms would thrive economically. Two

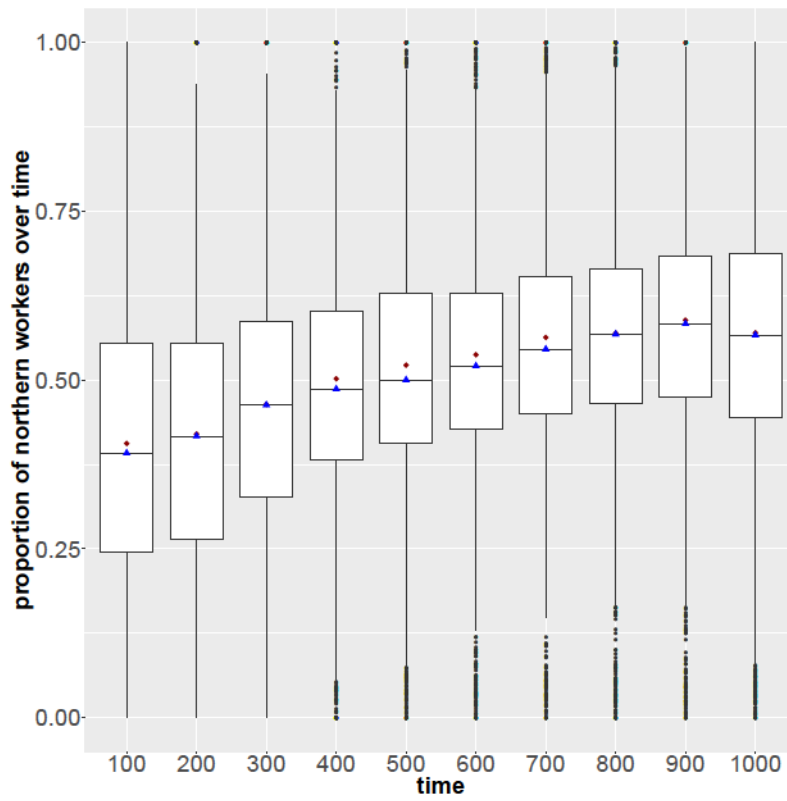


Figure 3.21: Mean proportion of northern workers in southern firms

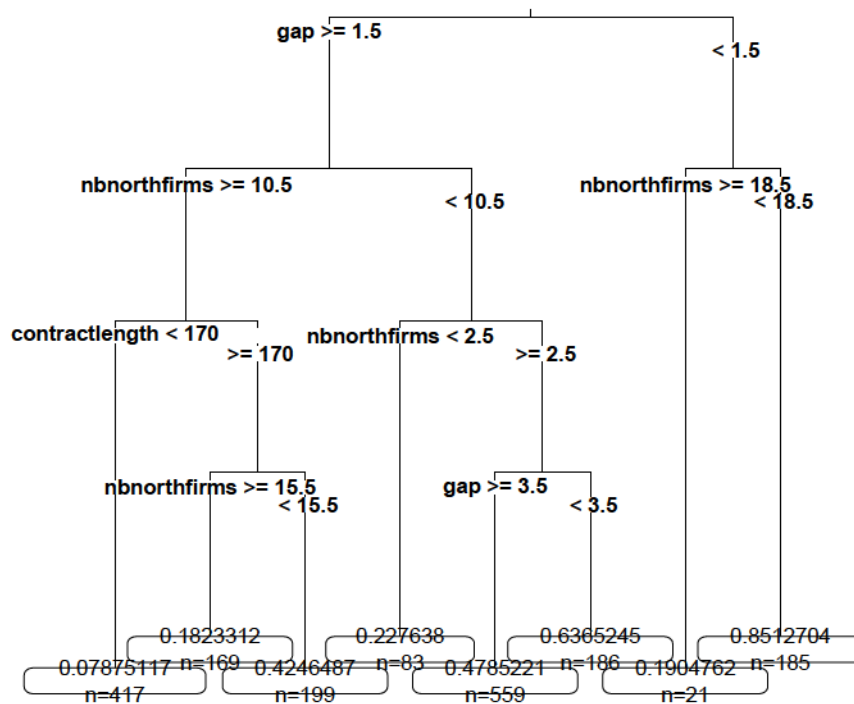


Figure 3.22: Regression tree: proportion of northern workers in southern firms

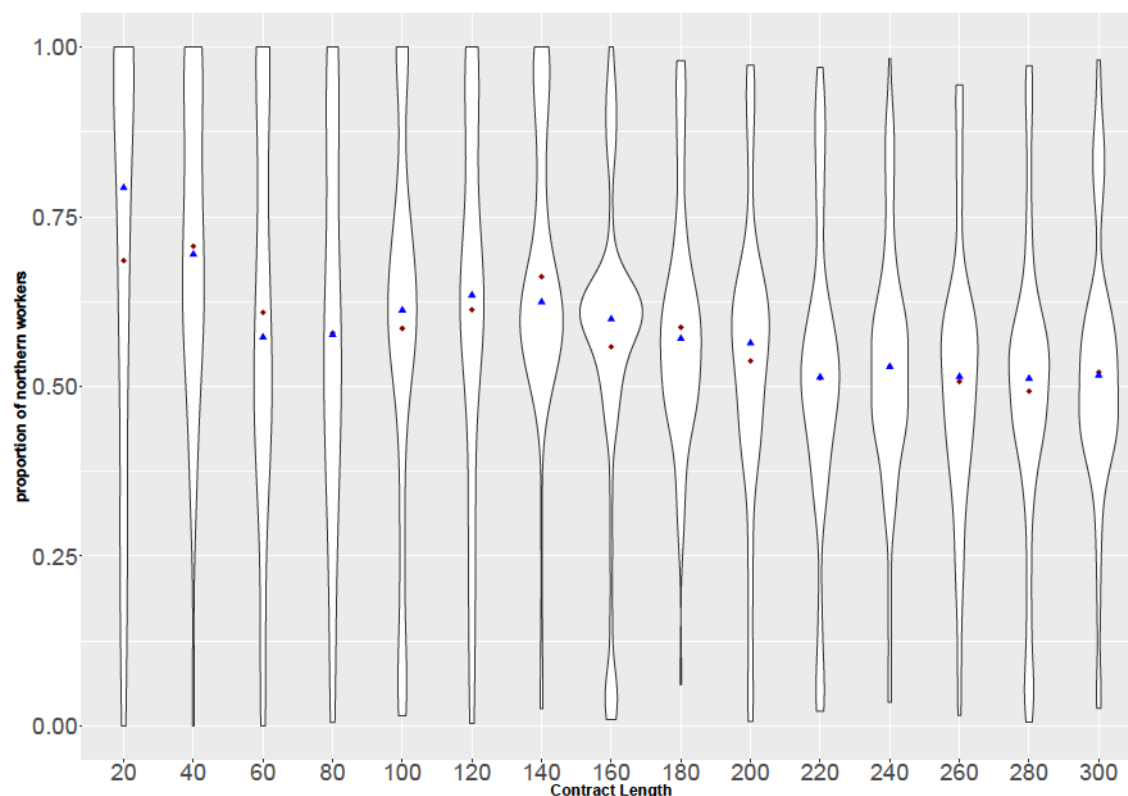


Figure 3.23: *Mean proportion of northern workers in southern firms according to contract length (at the 1000th period)*

explanations can be laid out: first there are not enough northern firms to recruit workers to allow a high turnover between northern and southern firms, and second, as southern firms are in numerical majority, they would hinder the progress of northern firms, if not reduce their chance of survival, thus making labour turnover between north and south even more scarce. If there are more than 50% northern firms in the industry, then the contract length plays a role: longer contracts increase the proportion, provided once again there are not too many northern firms (more than 16 firms is the threshold here).

Regarding the effect of the contract length, we would expect that longer contracts hinder the turnover of northern workers. Looking more closely at this variable through figure 3.23 we see that in the case of really short contracts, the mean proportion has a U-shape relationship with the contract length. For really short contracts we do observe that there is a high turnover, however, the observations are sparsely distributed. This means that these observations are highly contingent on other factors.

From our previous observations, we would suppose that this is due to firm performance. As contracts get longer, the proportion of northern workers increases, and more importantly, this distribution is more concentrated around those high values. For really contracts,

however we observe a decline in the northern workers proportion, suggesting that there exists an optimal contract length associated with the trade off between facilitating turnover and ensuring sufficient firm performance to permit the recruitment of those workers.

Proposition 3.16. *While short contracts improve labour turnover from northern to southern firms, the limited southern performance in those context would suggest that longer contracts ensure a more consistent result for firms in that regard.*

3.3.3.4 Beyond catching-up: can the local industry end up being more technologically advanced than the North? In only 3% of cases have southern firms managed to record a higher mean potential productivity than the northern firms. This indicator considers the whole active southern firms, and does not capture the case where for example only one southern firm succeeded at finding better technologies than the North. However, it tells us that it would appear that even the success of a limited number of southern firms does not spread sufficiently across the rest of the southern firms. It is a rather low statistic for the southern industry, considering that 47.5% of cases saw the South catching up to the Northern trajectory.

The regression tree on figure 3.24 shows the parameters which might affect the technological success of the southern part of the industry against the northern firms. The dependent variable is binary, takes the value one if there was a technological success for the South, 0 otherwise. The first leaf shows that in most cases (which corresponds to a gap of at least 1 and more than 2.5 northern firms), only 0.5% of cases succeed. The situation where this success is most likely is shown at the last leaf where 81% of southern industries in that case succeeded. It corresponds cases with low gap (0 or 1) and few northern firms. This is in general true for other leaves where the proportion of success is higher than 20%. Some other cases arise but given the low number of occurrences, the observations may not be significant. We can thus conclude that the rare cases when this happen corresponds to cases when southern firms have a strong numerical advantage over northern firms, and are very close technologically, which alludes to cases where northern firms suffered from the southern competition.

Proposition 3.17. *The southern firms are not likely to surpass technologically the northern firms. Only when the southern firms are able to compete and drive out northern firms will they be more likely to succeed in winning the technological race.*

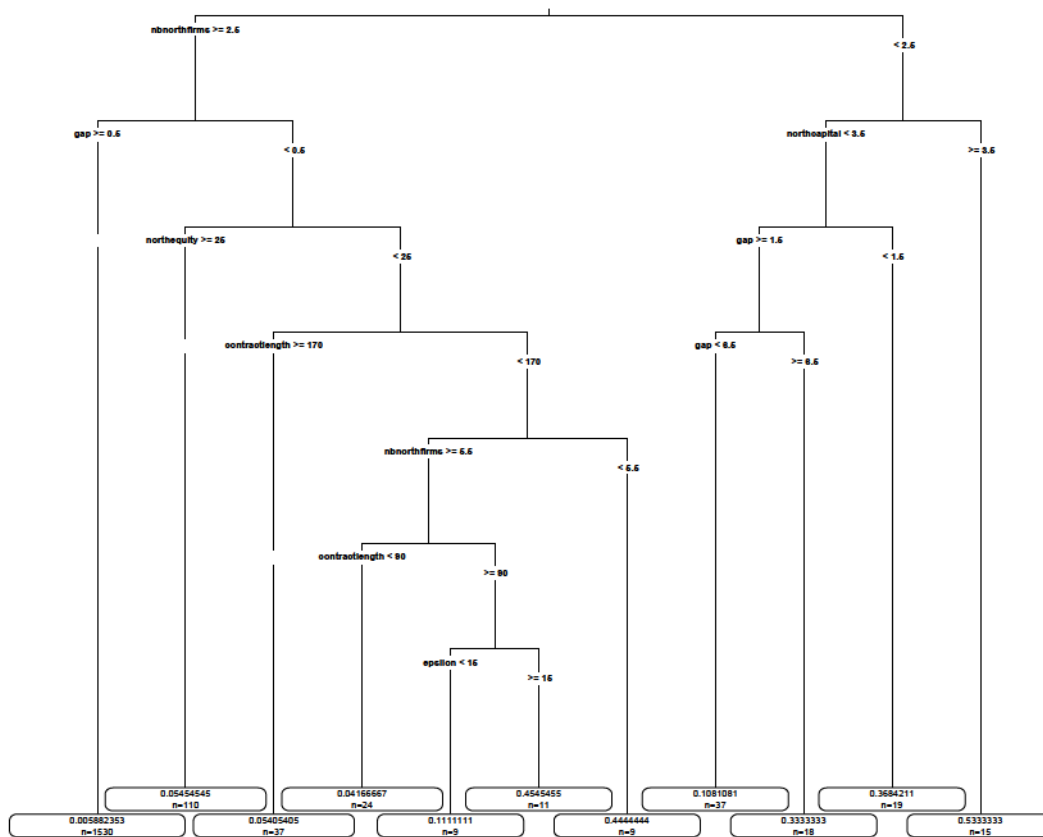


Figure 3.24: *Regression tree: proportion of cases where the whole southern industry on average has technologically outperformed the northern firms*

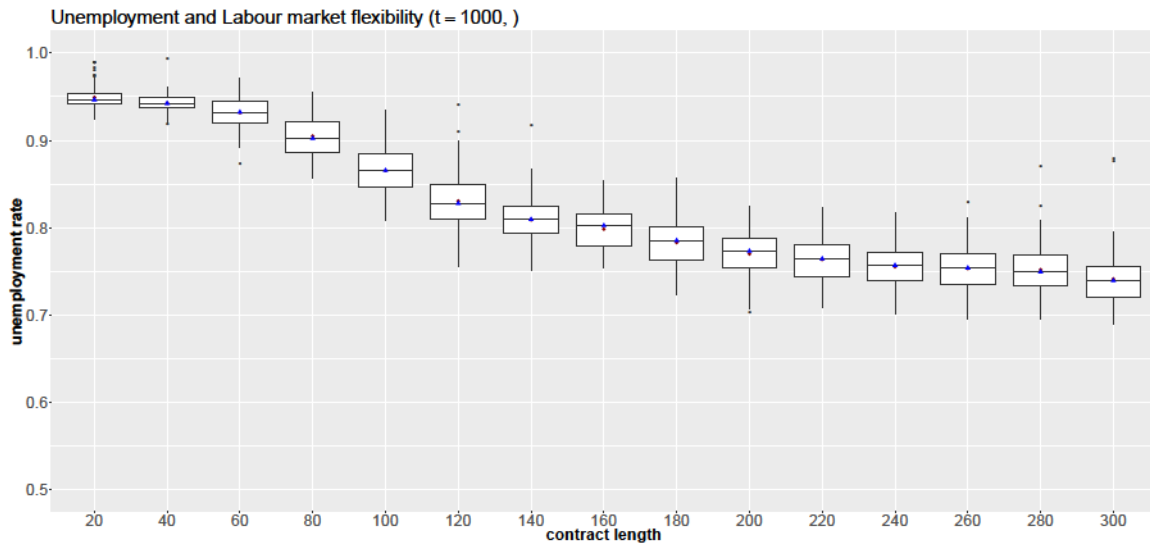


Figure 3.25: *Boxplots of unemployment rates observed according to the contract length (at the 100th period)*

This implies that there is still in general a technological advantage for Northern firms (who are not even switching trajectories). This means that once catching up happened some further efforts are necessary to improve the innovative performances of the southern industry.

3.3.4 The labour market and workers' development

Technological development happens in large part through the workers' contribution, since imitation plays such an important role. We here look at how the labour market behaves from workers' point of view in order to see what facilitates their skills acquisition and how southern firms can best benefit from those skills development.

3.3.4.1 Labour market flexibility and job creation There appears to be a decreasing relationship between labour market flexibility and the unemployment rate (figure 3.25). This might be explained by the positive consequences of longer contracts in the industry, which in return enables firms to employ more. The regression tree shows that the only treatment variable that affects unemployment is the contract length. The rest of the variation may be attributed to parametrisation of the model. Figure 3.26 shows the evolution of the unemployment rate over time for all the runs. The colour gradient paints runs with long contracts in light blue. As contracts get shorter, the colours get darker. The plots clearly show that longer contracts systematically register a lower level of unemployment. We note

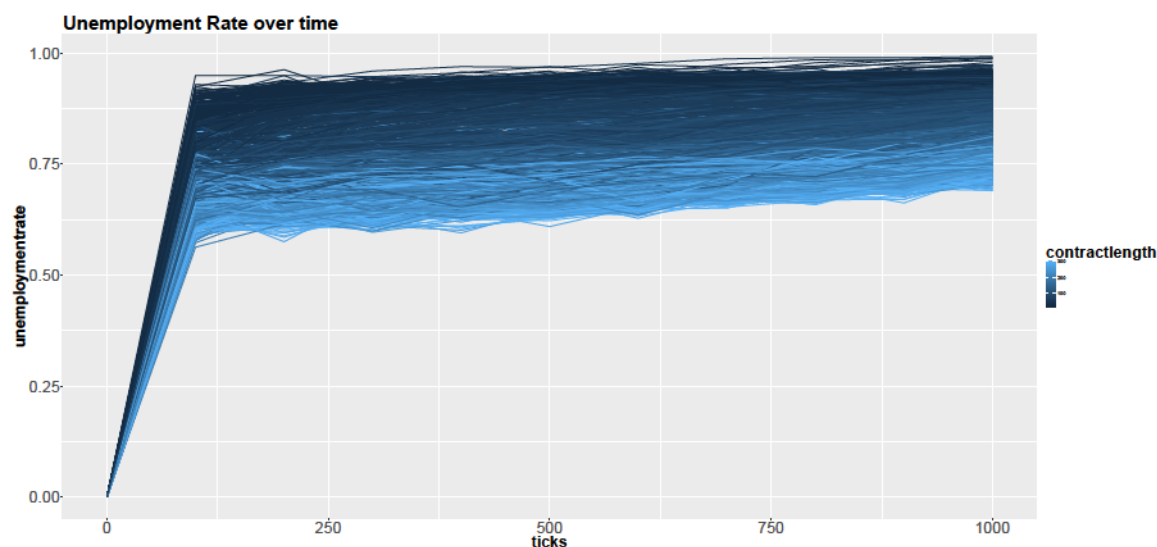


Figure 3.26: *Unemployment rates over time*

that in all the cases, after an adjustment period (due to exhaustion of the starting equity), the unemployment levels shoot up. It then continues to increase, though in smaller proportions. This is to be expected as the population increases and productivity growth reaches an asymptotic phase, thus making it unlikely that firms will continue their expansion, since the expansion of the firm is conditional upon productivity growth due to diminishing returns to scale.

Proposition 3.18. *A highly flexible labour market affects negatively firms performances which results in higher unemployment rates.*

Therefore, while labour flexibility can be a useful tool for short term adjustment, it prevents the training of workers and impacts long term firm performance.

A final comment regarding unemployment is the fact that it appears to be very high. This outlines a problem in parametrisation of the model. From our tests, the final unemployment rate reached is dependent on -among other variables- the number of firms, workers or even the parameters of the production function. The main issue that high unemployment generates is how to finance those unemployed workers, since their unemployment benefits are part of the demand. Taxes failed to adequately finance this government expenditure. We note however that the model did not exhibit inflation, which mitigates the potential issue here. Furthermore, this not financed demand could easily be interpreted as an external demand which purchasing power is inferior to our employed workers, though grows with the level of wages in the industry, as it was the rule for determining unemployment benefits.

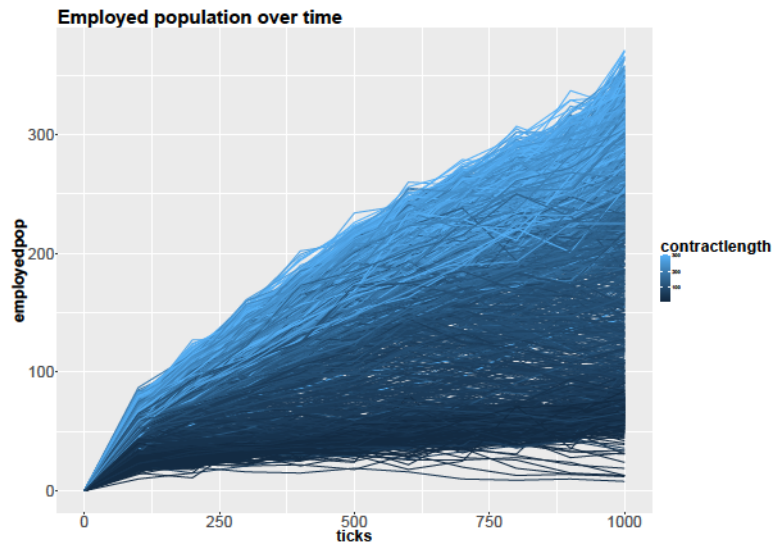


Figure 3.27: *Employed population over time*

Having high unemployment levels does not render our analysis void¹⁸. First we see that unemployment rates tend to stabilise over time, or diminish their growth, which suggest the existence of a natural level of unemployment in the industry, and more importantly, the population continues to grow at a rate superior to the growth rate of unemployment. This means that jobs are being created over time. This is clearly apparent in figure 3.27, which also shows that in industries with long contracts, there are even more jobs being created.

Therefore while high unemployment can be a legitimate concern here, in our case it is not synonymous with poor industry performance, since it does not stop the expansion of firms.

3.3.4.2 Wage levels We recall that wages should be ultimately the reflection of productivity levels. They are shaped theoretically by the skill levels of the workers, as firms would like to attract the most able workers in the hopes of gaining better productivity results and benefit from technological knowledge, under the assumption that higher skilled workers are more likely to have worked with better technologies. For this purpose, figure 3.28 plots for northern and southern firms the level of wages against the skill level (at the end of 1000 periods).

In both cases, there seems to be a positive relationship between skills and wages, with a strong level effect of the gap for northern firms (figure 3.28(b)). This effect is to be

¹⁸Though it does provide us with a perspective for improvement, as a more extensive version of this model would better control for unemployment.

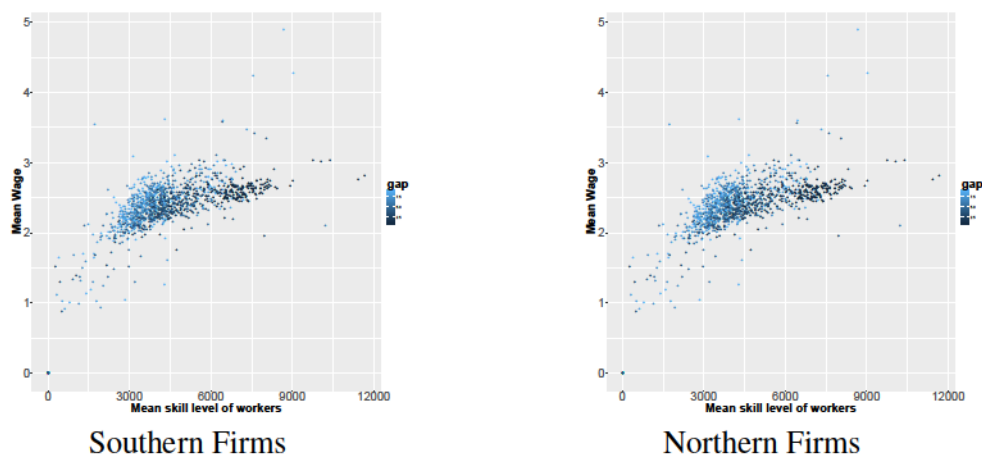


Figure 3.28: *Scatter plots showing the relationship between wages and skill level attained at the 1000th period*

expected since wages are paid on expected productivity, and the higher the gap the higher the productivity of northern firms. It is interesting to note that there does not appear to be such a level effect for the southern firms. At the end of 1000 periods, if the whole southern industry had caught up to the North, then the productivity levels observed should be higher, and wages should follow. The fact that the average wages in the south do not seem to replicate what we observe for northern firms echoes the results found earlier that if one southern firm manages to catch up it does not necessarily drives other firms up with it.

The regression trees (F.19 and F.20) in the appendix show which variables affect those two wage levels. For northern firms, it seems the only determinant is the technological gap. If the gap is at least 3, then number of firms matter. With a high gap, if there is less than 2 northern firms in the industry, the wage levels drop significantly. This is another argument for the importance of numerical superiority of southern firms. If there is a large majority of southern firms in the industry, then northern firms are less likely to progress (the same argument was made for the majority of southern firms). Looking at the tree for southern firms' wages, we find that a low level of northern firms drive up the wages. Contract length also plays a role. With longer contracts, wages are increased, thus emphasising the role of technological transfers. Workers can acquire more skills (which is linked to higher wages), and the firm is more likely to gain new technologies, which drives up productivity and thus wages.

Proposition 3.19. *The technological development of firms and workers enabled by longer contracts can raise the level of wages offered by southern firms.*

Finally southern firms seemed to perform better when there is a low technological gap, though the best results are not dependent on it. When there is a low technological gap, southern firms are more competitive and can resist better the strong influx of northern firms, thus progressing with more ease. However, since the technological gap is low, the perspective for growth are limited, which limits the level of wages obtained. When the gap is high, there is technically more room for progression, but the southern firms end up registering lower levels of wages because they fail to sufficiently develop technologically to attain those higher levels.

Proposition 3.20. *In the case of strong competition imposed by northern firms, southern firms will not be able to sufficiently grow to offer a similar level of wages as northern firms.*

A metric that is interesting to consider here is the differential of wages between northern and southern firms. To measure the level of inequality within the country, a measure "wage differential" is computed as $\frac{\text{south mean wage}}{\text{north mean wage}}$. As such, a value close to 0 means the inequality between northern and southern firms is really high (0 if southern firms die), a value close to 1 means wages are more or less the same, and a differential greater than 1 means that the southern firms pay their workers more than northern firms¹⁹. This reflects the level of inequality in the industry. In development economics (Aghion et al. (1999)) the inner inequalities existing in a country can hinder the development process, therefore the development of inequalities is something to be mindful about. First let us look at how this differential is affected by the different treatment variables (figure 3.29).

The tree is very similar to that of southern firms' wages, suggesting that it is by improving the southern firms wages that the inequalities will reduce. The northern firms do affect negatively the wage inequality (figure F.21 in the appendix), as their increased presence affects negatively the southern firms.

We see on figure 3.30 that the wage inequality strictly increases as the wages from the South decrease. If the northern wages had been following the southern wages, then the relationship between the differential and the level of wages in either part of the industry would not be so straight forward. This implies that when the northern firms experience low wages, the south experiences high wages (or at least competitive ones) and when the north is experiencing high wages the south is observing lower wages. Therefore the wage

¹⁹It happens in 9% of cases here

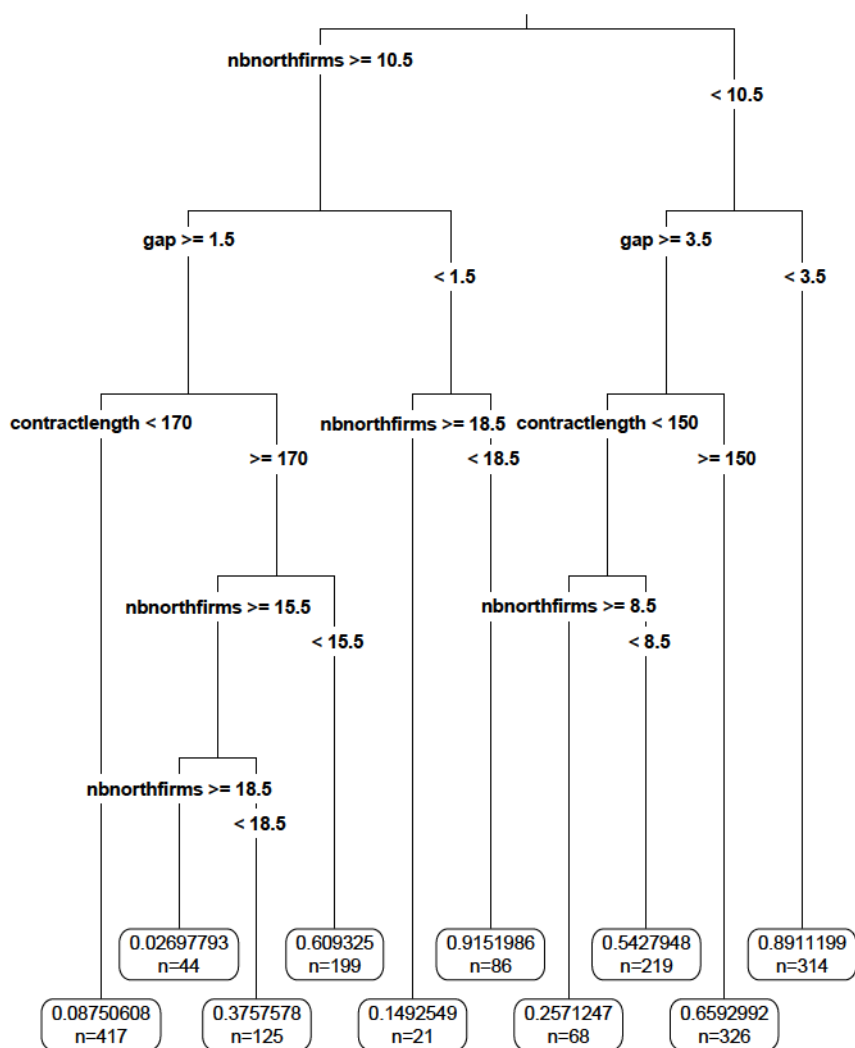


Figure 3.29: Factors affecting the wage discrepancy between northern and southern firms (1000th period)

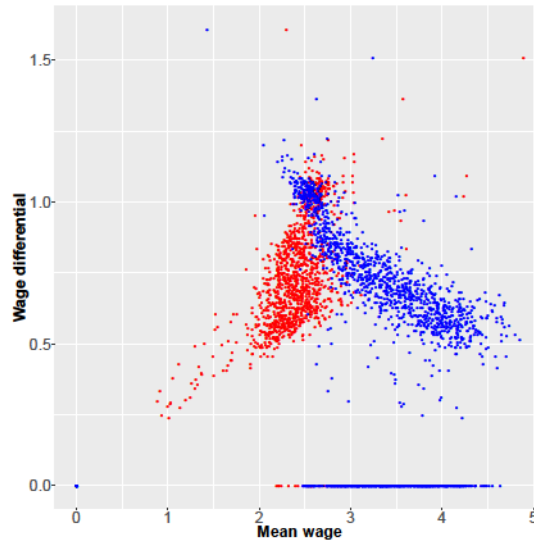


Figure 3.30: *Wage inequality and South (red dots) and North (blue dots) wage level*

differential not only shows that the South is lagging behind, but also that it implies that the as the South's performance drops, the northern firms' performances improves. This means that while one part of the workers is doing really well, the other part is being left behind.

The violin plot on figure 3.31 shows that as the initial gap increases, the wage ratio at the end of 1000 runs decreases. This confirms that despite the opportunities for growth of wages, southern firms do not manage to offer similar levels of wages as the north. The second violin plot (figure 3.32) considers only the cases where the southern firms had managed to catch up to the northern trajectory. We can see that the dispersion is more concentrated, which means that the results are more consistent. However, the wage differential keeps on decreasing as the gap increases, which means that even if technological catching up is observed in the industry, the entirety of the industry does not necessarily follow.

Proposition 3.21. *The wage disparity between North and South increases as the initial gap increases even if the South manages to catch up technologically.*

This proposition (in conjunction with previous observations) may indicate that the perspectives of catching up economically for firms may be grim. The fact that even in the case of technological catching up there is some important disparity in the country could potentially help argue that the presence of northern firms has a cost for the country, and not just local firms. While the technological transfers are helpful, the impact on the economy of particularly technologically behind countries might lead us to argue that perhaps the

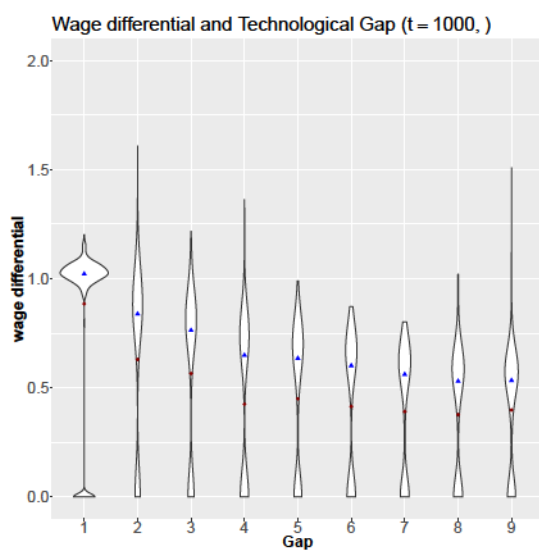


Figure 3.31: *Wage inequality and technological gap*

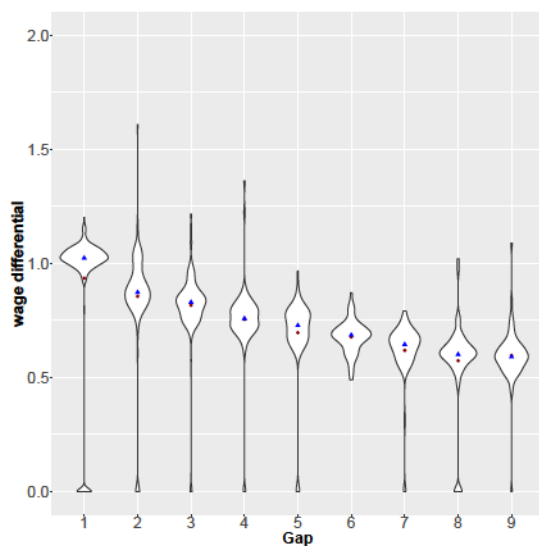


Figure 3.32: *Wage inequality and technological gap in caught up southern industries*

type of FDI studied here and the mode of transfer through the labour force are not to advisable for those countries.

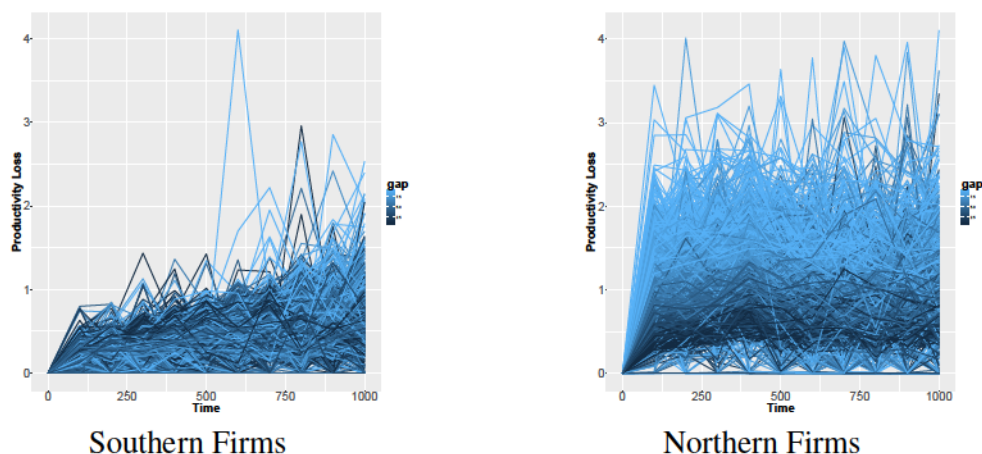
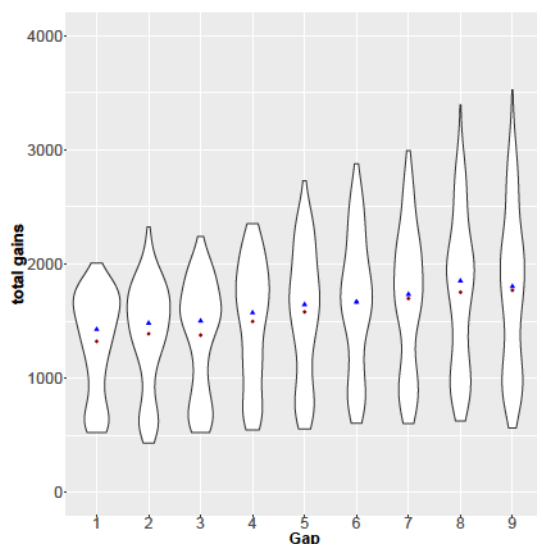
3.3.4.3 skill development: Are workers learning sufficiently? In order to study firm performance we had to look at the effective productivity of firms. The technological development of firms however improves their potential productivity. The difference between what the firm can achieve and what they do achieve lies with their own workers. If workers are not sufficiently trained, they cannot be efficient producers. The other concern is that less trained workers are workers who are less likely to transfer knowledge to their firms. For workers, there is a positive relationship between wages and skills (figure 3.28) for both northern and southern firms. Northern wages are also affected by the gap as we saw before.

This highlights an expected effect, that is skill development for workers lead to higher wages through higher productivity (also confirmed on figure 4 in the appendix). This means that skill development is crucial for workers' welfare, as well as firms' performance.

If we look at productivity loss (the difference between the potential productivity of firms and their effective level observed, due to the lack of skills and mismatch of skills of workers) over time for either northern or southern firms, we can see that the behaviour is not the same (figure 3.33). If we take the case of northern firms, we see that past an initial adjustment period, the loss incurred by northern firm is the same, but increases with the gap (figure 4). For southern firms, the loss incurred over time does not seem to change with the gap, but instead it seems to lightly increase over time (the mean is relatively stable, but we observe higher extreme values).

This tells us that the productivity loss increases with the technology level, whether it is because northern firms start with high technology, or because the south evolves towards those high technology). As this loss becomes increasingly more important, we can tell that the skill level of the workers does not evolve sufficiently over time to adapt to those higher technologies.

When we considered productivity losses, we saw that those losses became more important as the technologies become more sophisticated. We can also consider productivity gains in the industry as whole to check whether those losses experienced are signalling that the workers do not progress. A way to see how the training of workers affect the

Figure 3.33: *Productivity loss over time*Figure 3.34: *Total productivity gained by workers through training (at the 1000th period) per gap*

productivity is by aggregating all the productivity gains of workers following training. As we have described in the model, as workers complete their training they learn to work efficiently on their employer's technology. The variable studied here reports the total of productivity gained by workers as their experience and set of skills grow. While the value itself cannot be interpreted, we can see through the violin plot on figure 3.34 that as the gap becomes more important, the variance in productivity gains is larger, though on average the gains increase with the gap, which is expected as the productivity can reach higher levels in those cases, meaning the opportunities for productivity growth are more important.

Proposition 3.22. *As technologies become more complex, while workers can improve their productivity through training, these gains are insufficient to fully counterbalance the losses*

in productivity due to their inadequate skill level.

The skill system thus appears to function as expected. Wages and productivity evolve positively with the skill level, while the skill level can hinder the productivity of firms when it is not high enough.

4 Conclusion

The main focus of this chapter was offering a first ABM of North-South interactions, with a particular focus on the labour mobility transfer channel. The model is quite rich in mechanisms and dynamics, which lead to an extensive ABM. As the model is the first of its kind, the analysis of basic behaviour was necessary to validate it, and here it appears that the model works fine.

The model seems to adequately show evidence of the dual impact of foreign firms on a country. They can transfer knowledge while at the same time affect the performance of the local firms. When starting the analysis we were guided by three questions.

The first one concerned the extent that southern firms benefit from the northern firms presence. We find that having northern firms help in the catching up process as well as training the local labour force. However there is a clear competition effect when these northern firms are too numerous, they tend drive the southern firms out of the market.

Regarding the conditions that facilitate the development of southern firms, we find that having a large gap often means that they are not able to compete. This tells us that in the case of a large gap, FDIs might not be a suitable for technological transfers. This echoes results found in the literature that countries with low development levels failed to benefit from FDI induced technological transfers.

Additionally to benefit from technological transfers through worker mobility, the country needs to have rather long contracts in place to permit the training of workers so that they can effectively transfer competencies.

The third questions concerned which context is more favourable to northern firms. We find that northern firms perform better in high gap countries and when they can enter as a majority, which is in direct conflict of the situations that are most beneficial to southern firms. This implies that shaping an FDI policy for developing countries is quite complicated as there appears to be a direct conflict of interests between northern and southern firms.

A few effects were not present in the model, which leaves so perspective for improvements and extensions. For example, we fail to find effects of the education or the inner equalities on development outcomes. Nevertheless, as we are still able to draw clear results from the model as it is. The next chapter will thus focus on adding patents to the model so that we may study the impact of TRIPS on developing countries.

Chapter **4**

The effects of Intellectual Property Rights on emerging economies: an application of the North-South Agent-Based Model

1 Introduction

Technological progress is essential to the development process of countries. We have shown that whether technological progress should be based on imitation or innovation, developing countries need to acquire technologies that will allow them to reach a technological level comparable to that of currently advanced countries. In this chapter we will be studying the impact of technology policy, with intellectual property rights, on developing countries' catching-up process.

The global economy has been for a few decades now based on knowledge. Significant technological advancements is what made countries like South Korea join the league of advanced countries and those compete on innovation races. Economies started becoming highly dependent on the success of the high technology sector, this is when we started seeing governments pushing policies to protect the technological advancements. This wave of increasing intellectual property rights manifested in the U.S strengthening of the patent system. In conjunction with these evolutions, globalization of economies led to the need to protect technologies worldwide, and the agreements on trade related aspects of intellectual property (TRIPS) came to be. The Uruguay round (in 1994) of the WTO negotiation set standards for IPRs for all WTO members, which basically means that almost every

economy must be adhering to those standards. Developing economies were given a ten year period to change and adapt their policies to match the WTO recommendation. For these countries, it resulted in a strengthening of their IPR policy. In fact in the literature, when studying the impact of TRIPS on developing economies, it is implied that it is the impact of stronger IPR policy that is being studied.

The question we will be investigating here through a discussion of results found in the literature, and through a theoretical approach using the North-South agents-based model, concerns the efficiency of TRIPS as a development policy. More precisely our discussion will center on whether imposing high standards of IPR is beneficial to development process of emerging countries. The approach taken in the ABM part of this chapter revolves around the effects of the compliance with TRIPS by developing countries. While ABMs have been used to model patents (Vallée and Yildizoğlu, 2006), the particularities of the version presented here pertains to developing countries and their catching up process. As such it is not really the design of the patent system that is studied here but rather its strength and the decision made by government to comply with imposed standards.

After presenting the TRIPS policy and their implications for developing countries, we will look at the theoretical and empirical results found in the literature regarding their effects (more generally seen as a reinforcement of IPR policy in the South) on developing countries. In order to investigate what happens in a developing country when IPRs are in place we will add an extension to our North-South ABM that aims at modelling patents and their effects on technological catching up in the particular setting we established in chapter 3, that is an industry in developing country that has northern firms competing against local firms. We will analyse what happens to this industry if IPR come into play.

2 The contentious aspects of TRIPS policy

Before we get to the case of developing countries and their relationship with IPR policy, let us start with presenting the main notion discussed here: Intellectual Property Rights, and more specifically patents. Understanding their roles and usage will allow us to understand what is at stakes for developing countries.

2.1 A brief introduction on patents

Knowledge, from an economist's perspective, is generally considered to have the properties of a public good. It is non-rival, that is one agent's usage does not preclude that of another agent, and it is non-excludable, as one cannot prevent anyone else from using a piece of information (Arrow (1962)). The problem lies in the fact that knowledge creation is an expensive endeavour. This is especially true as technology advances and the costs of research and development associated with innovation are also increasing. This is partly what can explain the rising levels of expenses in R&D of today's firms. Without any form of regulation, essentially any knowledge made public may be used by any firm without having to undertake the risks associated with innovation. Akin to a free-rider problem, this creates disincentives for investing in R&D, as investing firms see the product of their investment potentially used by competitors, limiting the returns to the R&D effort. This is why firms may choose to keep their innovations secret. The creation of knowledge is, however, crucial to the development of countries. Governments thus have a vested interest in creating incentives for innovation. This is where patents come in play. Scotchmer (2004) in her comprehensive historical account of innovation incentives starting as far back as ancient Egypt, relates the story of the English prize system (17th Century), which consisted in the government handing out lump sum of money to inventors who solved a problem raised by the government (like a challenge). This system allowed for public disclosure of useful knowledge while rewarding inventors. As such, this is a good example of what incentives for innovation should look like in order for the inventors to disclose their invention for the benefit of society. Of course this system was not without its flaws (Scotchmer mentions for example that unannounced challenges resulted in scientists and inventors holding on to knowledge until there was a prize to gain). A variation of this system the ex-post version, consisted in handing out the prize regardless of whether or not there was a challenge involved, which poses the problem of estimating the value of an invention.

Patents, and intellectual property rights in general, thus aimed specifically at rewarding innovation and thus incentivizing it. Their current form consist in granting inventors a temporary monopoly over the exploitation of their invention. They also mean to disclose publicly the knowledge, as patents contain a full description of the technology involved.

Of course, the patenting system today is imperfect. When it comes to the reward aspect, the monopoly should be rewarding the inventor, which means figuring out the best patent design (the extent of the monopoly granted by patent protection) that optimizes the trade off between value to the inventor and social welfare. Undoubtedly, this is an impossible task, and certainly there is no one-size-fits all solution possible. Patents aim at preventing imitations (for a limited time). They can also have a negative effect on future innovations. This is particularly an issue due to the cumulative nature of technology, that is innovations are built on other innovations. Depending on the scope of patent protection in place, the policy can block innovations because they are considered too alike (the novelty criteria). While this could force inventors to come up with significantly different innovations, it could also prevent innovations that are actually novel. Narrower patents on the other hand could prove to be welfare reducing as inventors would only have to come up with small variations to offer a novel good and basically receive an extension on their previous patent, effectively granting them an unnecessary long monopoly. Trying to prevent imitations is also tricky, as broad patents can prevent the use of technologies that are not that similar, thus granting greater benefits to patent holders and impeding the progress of others.

Technically, the scope of patent protection could be divided in separated in two dimensions (Van Dijk (1994)), one that aims to protect against imitations (patent breadth), and one that aims at preserving the novelty requirement (patent height, as used by van Dijk (1994)). As Merges and Nelson (1990) point out, US courts decisions have in the past suggested that inventors should have a claim to the development of their innovations. When the novelty requirement is too low, patents are too easy to invent around, and Cohen et al. (2000) claims that this is a source of their inefficiency. The optimal design for the patent system has been debated. For example, Klemperer (1990) argues that long-lived but narrow patents are optimal (also Gilbert and Shapiro (1990)) because while they grant a long monopoly rent, the inefficiencies are easily corrected by the ease of obtaining close substitutes. Gallini (1992) argues the opposite, that is in favour of short-lived but broad patents; in a context where licensing is possible, this in theory maximises revenue for innovators, while creating a large cost for imitators and thus inciting innovation, without observing the inefficiencies of a monopoly over the long term. Early scholars would even argue that there should not even be a patent system in the first place, though the fact that our economies are built around it makes it impossible to go without one (Machlup (1958)).

These works on patent design emphasize the importance of the trade off when it comes to maintaining incentives while mitigating inefficiencies. Meanwhile, IPR policy has been shifting towards stronger patents in the West (see Hall and Ziedonis (2001)), whether it is in terms of length, or scope of protection. When it came to harmonising IPR policy worldwide, the WTO followed that trend, mostly as we will discuss in the next section, because of the influence of the most powerful nations.

2.2 The controversial aspects of TRIPS

The Trade-Related Aspects of Intellectual Property Rights (TRIPS) were signed at the Uruguay round of the WTO negotiations in 1994 in an effort to coordinate worldwide IPR policy. The subject matter was brought up by developed nations, mainly the US and the EU, wishing to prevent their innovations from being copied in developing countries where IPR policy was at the time more lax. TRIPS sets minimum standards for IPR policy for each signatory nation (which is basically the majority of countries). Those standards include a minimum length in the duration of patents (20 years), patents in domains that were not patentable before in certain countries (like pharmaceuticals), limits on the usage of compulsory licensing. As developing countries' original IPR policies tended to fall below those standards, there is a consensus in the literature that signing TRIPS is effectively synonymous with strengthening IPR rights. Developing countries were given a ten year period to adjust, so by 2005 most countries had aligned their IPR system with that of developed nations. Essentially this means that developing countries have had a stronger patent system imposed on them. Given patents can cause the inefficiencies due to monopolies and the fact that these economies rely on imitation as part of their technological development, it can easily be seen why TRIPS would not be to their advantage.

Wade (2003) in a critical article on development policy uses TRIPS as an example of a policy limiting the "development space" of developing countries. A multilateral organisation that is the WTO imposed rules on those countries, restricting their ability to choose their own policy. He particularly emphasises the unfairness of the agreement in three points. First, the enforceability of "developing countries' rights and developed countries' obligations" cited in TRIPS. Should developing countries have any dispute, the cost of instigating the claim (both in administrative and ripple effects terms) would be prohibitively high for developing countries, meaning that developing countries lose

significant power of negotiation. One such obligation is mentioned by Park et al. (2014), where they cite an article (Article 8.2) of the agreements that stipulates that "appropriate measures [...] may be needed to prevent the abuses [...] which affect the international transfer of technology". While it is mentioned that TRIPS aim at promoting technological transfers, there is no apparent enforcement mechanism of such principle, and it is unlikely that developing countries would claim against the failure of developed nations to do so. The second point is that TRIPS are meant to be a minimum standard, therefore any further discussion regarding trade and related treaties would entail a higher level of IPR protection. The final point concerns the fact that in virtue of their advantage (political and economic) over developing nations, advanced countries did not "place themselves under any obligations" and therefore skewing the agreement heavily in their favour.

This illustrates that the agreement itself is at its core in favour of developed country and probably not in developing countries' primary interest. An illustration of this given by Wade concerns the rising IPR costs in the South which would tend to greatly benefit the North.

It should also be noted that excepted some industries like pharmaceuticals, patents are not even used as the primary mode protection of important knowledge, as the firms tend to rely on other methods (secrecy, lead time Cohen et al. (2000)). Instead, patents nowadays tend to be used more as strategic tool to block the development of competitors rather than simply rewarding innovation. Therefore, the idea that TRIPS set up by developed countries are meant to foster innovation in the developing world is questionable. The motive was instead probably more to be patent fences against potential competitors.

By setting up such an aggressive policy, the idea that this might be an unfair play by the developed countries' can also be seen by considering their own development path. If we consider that today's developed nations used imitation to progress (as pointed out by Cimoli et al, among others) whether it is regarding copyrights infringements of Dickens by the Americans, to the use of lax policies ("petty patents") to allow for the technological development of Asian countries such as Taiwan, South Korea or Japan, the developed nations are just about preventing developing countries from using the same tools, consisting in acquiring and developing knowledge easily and cheaply, to permit further development. Essentially, this can be described as "kicking the away ladder", a term coined by F. List.

An often discussed ethical issue brought up by TRIPS is the protection on pharma-

ceuticals. Imposing protection on this particular sector poses the problems of raising healthcare costs and limits accessibility to drugs for developing countries. The issue at hand here is of course that hindering access to healthcare could have had catastrophic consequences for the population. A renegotiation in 2001 (the Doha Declaration) made this sector an exception, thus allowing for the local manufacturing and importing of generic drugs in case of a "national health emergency" in exchange of "adequate remuneration" and "reasonable commercial terms". Sykes (2002) argues that in light of the vagueness of these 3 notions, it would still appear that the policy remains in the hands of developed countries. A humanitarian disaster was avoided here, though this can serve as an example as how the strengthening of IPR could be unfair on humanitarian level towards developing countries. By imposing such strong protection on developing countries, their access to critical (and here life-saving) technologies can have truly negative consequences. The issue seems to be taking a more perverse aspect. Horner (2014) mentions the fact that India's becoming more prominent in the pharmaceutical sector and thanks to its strong capabilities in that domain, the existence of product patents in pharmaceuticals means that the production on the Indian market is starting to resemble more that of the North, to the detriment of the low cost generics production. This is especially concerning when we know that India had for long acted as the pharmacy of the developing world (Lanjouw (1998)).

Therefore, it would appear that not only do TRIPS agreements may have negative repercussions on the development of the developing countries, they may also lead to the ladder being kicked away even by developing countries with regards to their peers.

2.3 The expected impacts of strengthening IPRs in developing countries

The imposition of TRIPs by developed nations came from a need to protect their technology when entering a developing country. With the reinforcement of IPRs, countries should become more attractive to receive FDI and trade. In fact, Article 7 specifies that one of the aims of TRIPS is to promote technological transfers (Park et al. (2014)). While the rest of the article mentions the "mutual advantage of producers and users of the knowledge" and respecting a "balance of rights and obligation". As Wade explains, these

rights and obligations are arguably tilted towards the interests of developed economies. A few theoretical approaches appear to confirm this view. The study by Helpman (1993) through the use of a North-South model (using the trade channel) shows that strengthening IPR in the South only benefits the North by reinforcing their monopolies in the South. Smith (1999) finds evidence that strengthening IPR lead to an increase in US exports in those countries that did. However she notes adverse effects in the form of increased monopolies in countries with limited imitation capabilities. Glass and Saggi (2002) in their model find that an increase in IPR leads inefficiencies as the effort required for imitation becomes stronger, southern resources are allocated to imitation thus less available for MNEs to produce for them, production is relegated to the North to the detriment of future innovations. This can apply in cases where in Şener (2006) 's model, the South can start producing new goods developed in the North in two ways: either by imitation or through the implementation of multinationals. He finds similar results arguing that if Southern IPR are stronger then there is more incentives for multinational firms to set up an affiliate in the South, but the technology would remain internal, meaning that it is less likely to leak. Therefore, although there is an increase in FDI, technological spillovers are less likely to be observed among local firms. Parello (2008) argues that there are long term negative effects on the South industry due to its reliance on imitation. Furthermore, strong IPRs are not sufficient to attract FDI, low-skilled countries would fail to benefit from those FDI.

2.4 Positive evidence of the efficiency of stronger patent systems

On the side of arguments in favour of a stronger patent system in developing countries, Diwan and Rodrik (1991) argue that strong IPRs in the South are necessary for the North to develop the technologies they need, as the South lacks the capability to do so. Lai (1998) also points out relative to FDI that if there is a low level of protection then technology transferred by the foreign firms would not be at the highest level. The foreign firms being wary of the lackluster level of protection decide to only use low technologies in those countries. As such, with stronger IPRs in place northern firms should be more inclined to share higher technologies when investing in the South. Dinopoulos and Segerstrom (2010) find that a stronger patent system in the South leads to an increase in the rates of technology transfers, as foreign firms are more willing to export their technology, and more importantly they find that this effect dominates the negative effect due to the loss

of potential transfers from imitation. Empirically, Branstetter et al. (2011) find in their study on US MNEs that following reform, MNEs tend to expand their FDIs, resulting in overall industrial development. They specifically mention the positive impact on local suppliers. They also show that the benefit offsets the negative impact that stronger IPR has on imitation. Lee and Mansfield (1996) also find that FDI are strongly correlated with strong IPRs. Javorcik (2004) finds evidence that stronger patents in eastern European countries were conducive to more FDIs in high technology sector (that rely heavily on IPR), thus confirming the idea that better technologies would be shared by northern firms.

Another channel that must be considered here is the licensing channel. Intuitively we would expect that reinforcing IPRs strengthens the legal framework for licensing, and as such we should observe positive outcomes when it comes to northern countries licensing technologies in the South. Yang and Maskus (2001) through a theoretical North-South model show that increasing IPRs is synonymous of reducing imitation risks in southern countries and thus the price of technology licenses sold to southern firms, as there are less risks of imitations. As a result, more licensing should be observed in the South ultimately leading to technological transfers. This is also beneficial to northern firms who free up resources to focus on innovation while production can be done in the South. Therefore, strong IPR in the case of licensing should be beneficial to both North and South.

Vishwasrao (1994) argues that strong IPR encourages licensing but only for process innovations. Product innovations would remain northern monopolies. There is a positive impact to having process licenses sold in the South: southern firms could technically acquire those technologies without rivalry, which would foster a high technology competitive environment and thus encourage their technological development. In an empirical study on South Korea, La Croix and Kawaura (1996) shows that the country did benefit from technological transfers from the increased licensing they observed following a strengthening IPRs.

2.5 A U-shaped relationship between IPR and development

The differences of results and opinions found in the literature suggest simply that the level of IPR protection that would be most efficient for development cannot be uniform for all countries. Different development phases require different levels of IPR protection.

India managed to grow its pharmaceutical sector whilst the patent protection was removed in the country (from the 1970s to the introduction of TRIPS in the 1990s). The country developed high capabilities in that specific sector, when TRIPS came around the local industry was sufficiently strong, which explains why we observe a sustainable surge in patenting activity in that specific local sector (Horner (2014)). From this it is understood that the technological development in the Indian pharmaceutical sector is not necessarily attributable to increased in patent protection but more because India was able to build sufficient capabilities in that particular sector.

This serves as an example of the existence of a U-shaped relationship between desired IPRs and development. As countries build the technological capabilities (through imitation mostly), they require weak patent protection. When they start reaching a development phase more dependent on innovation, the need for stronger patents becomes evident. Similarly Cimoli et al. (2009) suggest that the distance to the frontier plays a role, countries with a small gap should be more likely to gain from TRIPS. Countries without innovative capabilities, and therefore relying on imitation are unlikely to benefit from a strengthening of IPR. This U-shaped relationship is shown both theoretically and empirically by Chen and Puttitanun (2005). Kim et al. (2012) use Korea as case study, as the country during its development phase was relying on weak IPR protection (utility patents) and as the technology became more sophisticated they started to switch to using more conventional and stronger patents as those used in Western nations. In terms of growth outcomes, Falvey et al. (2006) find that IPR protection is positively correlated with growth in low and high income countries. This suggests that emerging countries do not benefit from such policy, as they more dependent on imitation, which in those cases become more restricted.

Although this section appears to argue against TRIPS in principle, the positive evidence suggest that IPRs can play an important role in facilitating transfers, more specifically by inciting northern firms to share their technology. The existence of a U-shape relationship between IPR and development tells us that there are inefficiencies that emerge when countries rely on imitation, that do not seem to be offset by the potential for technological transfers. The model developed in the next section attempts to bring some light to the impact stronger IPR policy imposed on developing countries.

3 The North-South ABM with Patents

We propose to use fully the North-South agent-based model developed in the previous chapter, and here propose an extension that adds an IPR system in the southern country.

To summarize the story of the model, we consider the case of an industry in a developing country (the South) that has recently seen the entry of foreign firms from advanced countries (the North). We assume that the industry (southern and northern firms) caters solely to the local markets made up of households that work for those firms. Essentially, this describes the case of a southern industries that sees the entrance of more advanced competitors through FDI. The main advantage of the northern firms is that they use higher technologies situated on the technological frontier, while southern firms use technologies belonging to a lower trajectory. In this model, the presence of northern firms could potentially give rise to technological transfers by way of imitation and competency transfers through the local labour market. The idea is that the local labour force who gains employment at those northern firms have the possibility to learn new technologies and through labour turnover eventually transfer them to local firms. Through imitation and (incremental and radical) innovations, southern firms can hope to observe a technological transition towards the technological frontier to eventually catch up to their northern competitors. A complete account of the functioning of each component of the model, such as the technological space, the labour market or the training of workers, is given in chapter 3.

Developing countries are heavily incited to conform to the strong standards of IPR set by developed countries. This is due to WTO recommendations, which has added adherence to TRIPS mandatory for membership. One of the main questions of this thesis is if strengthening IPR in developing countries could hinder, or facilitate development. As we have seen in the previous literature review, the effect of stronger IPRs on technological transfers varies according to the channel through which those transfers occur. Our basic model here focuses on transfers through FDI with imitation through labour turnover. It appears to be clear that in the case of horizontal transfers, which is the current case, firms are not willing to share information with their competitors, and would therefore seek to protect their innovation. This protection can take many forms, in the present model, firms can try to protect their technology by either keeping it secret, or by patenting it.

A trade secret has the advantage of low visibility. However, if it is accidentally discov-

ered, imitation is straightforward, provided the imitating firm has a sufficient ability to do so. Additionally, if a former worker is employed by a new firm, then she has the possibility of communicating this technology to her new employer, without any repercussions. This is where the weakness of the trade secret is found, once it is uncovered, there are no legal recourses to stop the imitation.

If a firm chooses to patent the technology, then this technology may not be imitated or used by a former worker while the patent is active. However, a patent has the disadvantage of providing a clear descriptive of the technology, thus making it visible and easy to imitate (though some degree of firm capability is still necessary), provided the IPR system is not well-enforced. While we acknowledge that patents have been found empirically to not be a source of knowledge for firms, representing this mechanism in the model allows us to see if and how developing countries can benefit from a disclosure of technology from advanced firms. Below is a description of the patents extension.

3.1 Defining the different patent parameters

The patent system of a country is defined by the type of protection granted by the patent and the costs.

3.1.1 Patent costs

When a technology θ on a given path is patented, this means that it may not be copied for a given number of periods, we call this parameter the patent life parameter. Each technology may be patented up to the maximum of the patent life. This means that firms can also choose to end the patent protection earlier than the patent life allows. Patenting is costly (mostly in legal fees), therefore patents have a fixed patent cost. For simplicity, we elected to not include a renewal cost and we assume that it is included within the initial cost.

3.1.2 Patent life

Patents can be kept alive for a maximum number of period, the patent life parameter. This patent life parameter does not mean that patent necessarily lasts this long, they can be cut short if the firm estimates that the patent is obsolete and thus forgoes the renewal

of the patent. When a patent is no longer active, the technology is still publicly available, however given that the patent becomes a part of the "state of the art", if a firm discovers the technology it cannot patent it.

3.1.3 Patent breadth

Patents block imitation of the given technology but also close imitations. What is considered close imitations is described through the patent breadth parameter. Since the purpose of this model is not to test patent design, we kept this as simple as possible. A patent protects a technology and similar technologies on the same trajectory only. What are considered similar technologies by the patent office is defined by the patent breadth. On a given path p , two technologies θ_1 and θ_2 are considered similar if:

$$|\theta_1 - \theta_2| \leq \text{patentbreadth} \quad (4.1)$$

The breadth of patents is a policy parameter that does not change throughout time. The degree of similarity set by a country partly tells us how strict the design of patent system is. Broad patents cover more technologies, and can therefore be an obstacle to the technological advancement process.

For example, if in the country the patent breadth is set at 2, then a patent on technology $\theta = 4$ protects 2 steps further and ahead, so it would essentially cover any $\theta \in [2, 6]$.

3.2 Enforceability

One last consideration to have here concerns the enforceability of IPR policy. In developing countries, the political climate may not always be auspicious for enforcing IPR policies. While this can be due to non-IPR related factors, such as a high level of corruption, poor control of the judiciary systems, it can also very well be a choice made by the country itself. Lesser (2001) includes enforcement when they build a IPR strength index, specifically citing Kaufmann et al. (1999) "perception of the quality of governance may often be as important as objective differences across countries". Beyond the theoretical scope of patent protection, such as what is mandated by the patent breadth and the patent life, there is the choice made by countries to enforce those theoretical policies. An example would be Brazil (Wade (2003)), when the government decided to forego certain categories

of patents, despite having signed TRIPS agreements, as they were deemed to be unfair. The enforcement level expresses the commitment a country has to uphold IPRs. This is all the more relevant as most developing countries signed TRIPS, so in theory they all have the same (minimum) levels of IPR protection (which as we have discussed is a strong level due to the fact that they are imposed by advanced economies). Their willingness to play by the rules however, is what can arguably be defined as the strength of their patent system. We call η this enforceability factor, with $\eta \in [0, 1]$. 1 being the case of full or perfect enforcement, and 0 the absence of enforcement.

In the model, this enforcement parameter intervenes when firms are faced with a technology that is protected under an active patent. This can happen if they make an innovation that falls under the breadth of an active patent, or if they attempt to imitate a protected technology. If enforcement is perfect, then in either of those two cases, the firm will not be able to use the technology. If enforcement is imperfect, this means that firms might be able to use a technology despite the presence of an active protection. The likelihood of being successful at infringing a technology increases as enforcement decreases.

With the parameters defined, we can now look at how firms decide to patent depending on those patent parameters.

3.3 Decision to patent

A patent must be filed at the period the technology is found. This means that if the firm refuses to patent a new technology, then by default it opts to protect it through a trade secret, and this may not be revertible. The decision to patent depends on affordability and risks. Affordability is straightforward, after having spent on R&D and innovated, firms check if their equity allows to file for a patent on the new innovation they made at that period.¹ If they do not have sufficient funds, then by default the invention is protected through secrecy.

The risk aspect of this decision looks to answer the question: If the firm does not patent, how likely is it that other firms will come up with a similar technology (or uncover the trade secret)?

Firms know that if the technology is close to what other firms are doing then risks of

¹The payment of patent fees goes to the government account.

infringements (accidental or not) are higher. On the other hand, if the new technology is far enough from the rest of the industry, then risks are smaller and in fact divulging the technology might play against them in the longer term, as when the patent will be dropped the technology will be easier to imitate. Firms thus evaluate where their new invention falls in comparison to the rest of the industry. The technologies θ_i used by competitors are not observable variables, rather firms have knowledge of the level of productivity in the industry. Therefore the only way they have of figuring out where their technology falls is by comparing productivity levels.

Since firms do not know the productivity levels associated with their new invention, they consider their current level of effective productivity to get a sense at where they are in the industry. Then they check the state of the industry.

- If the productivity achieved by the firm is situated in the first quartile of the industry, then the technology is considered to not be worthy of patenting.
- If their productivity exceeds an upper bound, the firm considers its technology to be too advanced and refuses to patent it. This upper bound is determined through multiplying the third quartile by the η patent enforcement parameter. If there is perfect enforceability, firms will not patent technologies with productivities in the third quartile. With lower enforceability, this upper bound decreases, meaning less advanced technologies will not be patented, and chosen to be kept secret as the risks are considered greater due to potential failure in enforcement.

In extreme cases, such as $\eta = 0$, the upper bound falls below the lower bound (first quartile). This implies that no innovation will be patented. Therefore we expect that states where enforcement is low are basically states with no IPR protection. We note that those bounds are determined in the industry each period prior any technological development (innovation and imitation) takes place for that period. They are thus based on the state of technology in the previous period.

Temporality does play a role in the patenting process. It is possible that two innovations are made in the same period, though only one will get the patent. The firm who gets the patent is determined randomly.² Therefore in the case of similar innovations, the attribution of the patent is left to chance.

²The way NetLogo works is by going through every firm in a random order and making them go through the technological development process one by one.

In this model, for simplicity we elected to not fully represent the firm's decision to renew patents. Instead, we assume that patents are lived out until the maximum number of periods allowed (defined by patent life) or until the technology they contain becomes obsolete (whichever comes first). Obsolescence is defined as when the productivity associated³ with the patent falls below the first quartile of productivities in the industry. When this happens, the patent is dropped.

3.4 The global knowledge stock

The public disclosure of patents results in what we call the global knowledge stock GKS_t . The global knowledge stock is the accumulation of technologies publicly known. As we have seen in chapter 3, the global knowledge stock contributes to increasing the probability of successful innovation and imitation. Each technology (θ, p) patented contributed to the global knowledge in similar ways that a technology learned by a firm benefits its knowledge stock. Therefore for each patent filed with each technology (θ_j, p_j) , the global knowledge stock increases by:

$$\ln(1 + p_j) * \ln(1 + \theta_j)$$

The global knowledge stock is thus the sum of this component for each technology j patented. Let PAT be the set of technologies patented, we have

$$GKS = \sum_{j \in PAT} (\ln(1 + p_j) * \ln(1 + \theta_j)) \quad (4.2)$$

3.5 Effect on innovation

Patenting affects the innovation process in that when a firm is successful in innovation, it must now check of the new technology is not infringing on current patent. In any case the new technology still contributes to knowledge stock. What changes is whether or not the firm will be able to use the technology.

If the innovation process is successful, the firm has a new technology which has a

³Firms who file a patent associate their current level of effective productivity with the patent. This underestimates the potential productivity of the patent. It reflects a loss for the firm due to their incomplete information

specified θ and trajectory. What is left to for the firm is check if the technology can and will be patented, or if it can be used. After the innovation is successful, five situations may arise:

[label]= **Case 0**]The innovation falls within the scope of an active patent which the firm does not own. The innovation falls within the scope of an inactive patent which the firm does not own. The innovation falls within the scope of an active patent which the firm owns. The innovation falls within the scope of an inactive patent which the firm owns. The innovation does not fall within the scope any active or inactive patent.

These scenarios and the outcomes are summed up in table 4.1 In the first case, it is clear that the innovation may not be patented at all. It should not be used either. However, since we are operating in countries where the enforcement of IP laws may be low, we can consider the case where the firm does attempt to use this innovation. As we mention it in the section on patents, the enforceability parameter is $\eta \in [0, 1]$ where 1 means perfect enforceability. Here, the parameter will also reflect on the probability that the infringement will be carried out by the firm. Specifically, the probability of successfully infringing on the patent is $1 - \eta$. Therefore, if the innovation falls under case 1, the firm will attempt to infringe. If the infringement is successful, the technology becomes available to be used by the firm. To simplify the problem, we assume that once the firm has been successful in the infringement, the technology may be used in later periods without having to test for infringement again.⁴ This also implies that if a patent for another technology is filed at a later date and ends up covering an existing technology, the patenting firm may not stop existing firms from using their previously found technologies. It may, however, hinder further innovations based on that technology.

In the second case, there is no question that the firm may use this technology if it so wishes, however patenting is not possible.

In the third case, a patent may not be filed either, however, the firm may freely use this technology since it would only be infringing upon their own patent. This also applies in the fourth case.

In the fifth case, a patent can be filed, and the technology can be used. We note however than one does not imply the other, the firm can file the patent without using the technology

⁴This simplification is necessary so as not to burden the execution time by excessive patent checks

and vice-versa.

Scenario	Is there a Patent?	Active?	Owner?	Usable?	Patentable?
1	yes	yes	no	no	no
2	yes	no	no	yes	no
3	yes	yes	yes	yes	no
4	yes	no	yes	yes	no
5	no	N/A	N/A	yes	yes

Table 4.1: *When can an innovation be patented and/or used ?*

We should note that when checking if an innovation can be patented, firms have to make sure that if a patent is filed, the scope of protection of that new patent will not overlap with the scope of another patent (active or not). If there is an overlap then while firms can use the technology, they cannot patent it. Furthermore, for simplicity, we assume that if a firm uses a technology in secret (i.e. they have not filed a patent for it) and competitor finds a similar technology and decides to patent it, in the case that it results in patent covering the first firm's technology, the firm is still able to use its technology (the patent cannot prevent anyone already using the technology from using it).

We recall from the description of the base model that the disclosure of technologies could increase the probability of making successful innovation, but also of making radical innovation as the technological frontier becomes more visible.

3.6 Effect on imitation

Patents make technologies visible. Therefore any technology which has a patent may be imitated and become part of the spectrum which may end up being imitated. The fact that a patent is published make those technologies easier to imitate, therefore their likelihood of successful imitation is increased. A further increase of probability is also applied if enforceability is not guaranteed, as discussed above.

Since the mode of transfer is still based on labour turnover, for a technology that is patented to be imitated, the firm needs to have at least one worker who knows the technology. If we recall that in chapter 3 the set of technology that could be imitated was a small proportion of currently used technologies by competitors, the idea being that firms could only observe a handful of competitors. By publicising their innovations, firms make those visible to other firms. Therefore, with the addition of patents in the model, firms now also add a set of technologies determined by a fixed proportion of "superior" patented

technologies (active or inactive patent). Here as well as in the base model a technology is considered superior to that of a firm i if it is either on a higher technological trajectory, or of it is on the same trajectory but with a higher θ than the current technology.

The set of technologies that a firm may imitate at each period is thus now composed of technologies observed by "spying" on competitors, as well as a percentage of patented technologies. The condition for the successful imitation of each technology remains that the firm must have at least one employee familiar with the technology. The imitation process remains the same: we compute the probability of imitating by using the score function described in chapter 3, and then one of the target technologies is picked through a weighted random draw. A few points are affected by patents here :

- The publication of patents makes the likelihood of being successful at imitation higher, since it raises global knowledge.
- Adding more technologies to the set of target technologies increases the opportunity variable (we recall it is defined as the sum of weights given to each target technology, therefore adding more technologies will increase the opportunity variable). This in turn will increase the likelihood of being successful at imitation.
- The probability weights associated with each technology is modified by the presence of patents.

Regarding that last point, we note that publicising a technology facilitates the imitation, therefore, the weight increases by the presence of a patent on that particular technology, regardless of whether the patent is active or not. There is a second effect of patents linked to the active status of a patent. If a patent is active, the likelihood of being successful at imitating the technology depends on the enforcement in the country, η . If $\eta = 1$ then there is perfect enforcement and the technology in question cannot be imitated at all, therefore the probability weight associated with that technology falls to 0. In the other extreme case, $\eta = 0$, there is poor enforcement of patents in the country, which means that the presence of patents only increases the likelihood of imitating that technology, there is no negative effect. To model this, let D_1 be a dummy variable which takes the value 1 if there is an active patent on a given technology (0 otherwise), and D_2 a dummy variable that takes the value 1 if there is an inactive patent on the technology. If a target technology has been added to the set of imitable technologies at this period through observation of

competitors, and does not happen to have a patent on it, then $D_1 = 0$ and $D_2 = 0$. The weights associated with each technology are calculated in a similar way as described in chapter 3, with the addition of the previously described patent effect. In chapter 3 the weights for each target technology (j) for a given firm i were:

$$weight_{i,j} = \frac{1}{(w_1 * gapfactor_{i,j} + 1)(w_2 * distancefactor_{i,j} + 1)}$$

When taking into account patents, the weights become:

$$weight_{i,j} = \frac{(1 - D_1\eta)(1 + D_1 + D_2)}{(w_1 * gapfactor_{i,j} + 1)(w_2 * distancefactor_{i,j} + 1)} \quad (4.3)$$

With this specification, if there is no patent on a target technology, the weight calculated revert to the specification from chapter 3. If there is an inactive patent, then the factor linked to enforcement ($1 - D_1\eta$) does not matter, and only the factor related to the positive impact of patents ($1 + D_1 + D_2$) counts. Essentially, the existence of an inactive patent doubles the weight associated with the target technology.

4 Are strong IPRs effective in helping the technological development of emerging economies?

4.1 Setting up the patents experiment

Similarly to what was done in chapter 3, the IPR extension was programmed onto the base model on NetLogo 6.0.1. A similar experiment was run, this time focusing on patent variables. We note that our goal here is not so much to test the design of the patent system, but rather the impact of the inclusion of strong IPR system on development outcomes in the South so that we can analyse the consequences of the imposition of a stronger IPR policy on southern firms, such as what has been seen with TRIPS.

The experiment variables here can be separated in two groups, situation variables, and patents variables. The situation variables are the variables that impacted catching up and firm performance as saw in the base model: the number of northern firms, the size of the gap, and contract length. The patent variables include patent life, patent breadth and enforcement. The variables used, as well as their range are described in table 4.2.

We run the model 2000 times, where each run is 1000 periods. We record the results every 100 periods. We use the results generated by those simulations to answer the following questions often studied in the literature.

Variables	Name	Range	Increments
Number of Northern firms	<i>nbnorthfirms</i>	[2;19]	1
Technological Gap	<i>gap</i>	[0;8]	1
Contract Length	<i>contractlength</i>	[20;300]	20
Patent Life	<i>PatentLife</i>	[40;400]	20
Patent Breadth	<i>PatentBreadth</i>	[0;20]	1
IPR Enforcement	<i>enforce</i> (η)	[0.1;1]	0.1

Table 4.2: *Treatment variables*

4.2 Results

In an attempt to contribute to the answer to the question of the effect of stronger IPR laws in developing countries on their technological and economic development, we thus use the previously mentioned simulations to observe what happens to southern firms, northern firms and the country itself depending on different configurations.

4.2.1 Effects of patents on catching-up

As the inclusion of IPR is an extension to the model developed in chapter 3, we begin by a similar starting point, that is the effect of patents on the probability of catching up. We recall that we computed a dummy variable that took the value 1 if technological catching-up was observed during the course of each run of the simulation, and 0 otherwise. Technological catching-up is considered successful if at least one southern firm managed to reach the northern trajectory. It does not matter if the whole southern part of the industry is left behind, or even if they are not as efficient as northern firms, the important part is that at least one southern firm managed to learn the northern technology. A first observation can be made that is we find that catching up succeeded in 65.3% of the runs. We recall that in the previous chapter, without the IPR system, the rate of success was 47.5%. This suggests that the inclusion of patents can have a positive effect on the development process.

To investigate further and for the purpose of offering some comparison between a model with IPR and one without IPR, we keep the same method as the previous the chapter and run a logit regression on the probability of catching-up, this time with the inclusion of

the number of patents filed by both northern and southern firms (adjusted by the respective number of firms. The model estimated by maximum likelihood is:

$$\begin{aligned} \text{success} = & \beta_0 + \beta_1 \text{nbnorthfirms} + \beta_2 \text{nbnorthfirms}^2 + \\ & + \beta_4 \text{Gap} + \beta_5 \text{Gap}^2 + \beta_6 \text{contractlength} + \beta_7 \text{innovations}_{\text{south}} \\ & + \beta_8 \text{imitations}_{\text{south}} + \beta_9 \text{patents}_{\text{south}} + \beta_{10} \text{patents}_{\text{north}} \end{aligned}$$

The correlation coefficient for these variables are given in table 4.3. While some variables are correlated, the coefficients never exceed 0.40, which suggests low levels of correlations, and allows us to proceed with the logit estimation.

	nbnorthfirms	nbnorthfirmssq	gap	gapsq	contractlength	south_innovations_adj	south_imitations_adj	southpat_adj	northpat_adj
nbnorthfirms	1.00	0.98****	0.00	0.01	-0.02	-0.38****	-0.37****	0.21****	0.12****
nbnorthfirmssq	0.98****	1.00	0.01	0.02	-0.03	-0.40****	-0.37****	0.20****	0.10****
gap	0.00	0.01	1.00	0.96****	0.02	0.20****	-0.25****	0.27****	0.06**
gapsq	0.01	0.02	0.96****	1.00	0.02	0.19****	-0.15****	0.26****	0.05*
contractlength	-0.02	-0.03	0.02	0.02	1.00	0.36****	0.40****	0.10****	0.05*
south_innovations_adj	-0.38****	-0.40****	0.20****	0.19****	0.36****	1.00	0.45****	0.33****	0.18****
south_imitations_adj	-0.37****	-0.37****	-0.25****	-0.15****	0.40****	0.45****	1.00	0.09****	0.09****
southpat_adj	0.21****	0.20****	0.27****	0.26****	0.10****	0.33****	0.09****	1.00	0.44****
northpat_adj	0.12****	0.10****	0.06**	0.05*	0.05*	0.18****	0.09****	0.44****	1.00

Table 4.3: correlation coefficients of the regression variables

We report the results of the estimation model (2) in table 4.4 as well as the results from the previous model (1) that did not include patents.

As we can see, the number of northern patents plays a significantly positive role on the success of catching up. When northern firms patent their innovations in the south, the likelihood of having at least one southern firm technologically caught up increases. What we can deduce from this, is that the publication of northern technology makes it easier for southern firms to learn, which results in in radical technological change, either through imitation of patents or through facilitating radical innovation. The rest of the analysis will focus on looking more closely at this apparent positive effect in order to bring an answer to the question of whether a strong IPR system is desirable in the South.

4.2.2 The apparent positive impact of a strong IPR system

Figures 4.1 and 4.2 show respectively the level of southern firms average productivity and average profits without and with a patent system in place. While there does not seem to be much of a benefit for countries with a low gap, countries that are further behind appear to be much better off with a patent system due to imitations made possible. Countries with a high gap failed to increase their productivity, despite the fact that much better

	<i>Dependent variable:</i>			
	successcatchup			
	Logit (1)	Marginal Effects (1)	Logit (2)	Marginal Effects (2)
nbnorthfirms	0.484*** (0.077)	0.117***	0.549*** (0.058)	0.093***
nbnorthfirmssq	-0.021*** (0.003)	-0.005***	-0.017*** (0.003)	-0.003***
educational gap	-0.008 (0.005)	-0.002		
gap	-1.596*** (0.158)	-0.385***	-1.271*** (0.130)	-0.216***
gapsq	0.131*** (0.016)	0.031***	0.099*** (0.013)	0.002***
contractlength	-0.003*** (0.001)	-0.001***	-0.004*** (0.001)	-0.000***
south_innovations_adj	0.019*** (0.001)	0.004***	0.017*** (0.001)	0.003***
south_imitations_adj	0.093*** (0.019)	0.022***	0.067*** (0.013)	0.011***
south_patents_adj			-0.038 (0.052)	-0.006
north_patents_adj			0.487*** (0.099)	0.082***
Constant	-3.557*** (0.572)		-4.765*** (0.450)	

*p<0.1; **p<0.05; ***p<0.01

Table 4.4: *Probability of catching up: Logit regression output*

technologies were out there. With patents however, they do succeed in increasing their productivity and appear to be better off.

Proposition 4.23. *A patent system contributes positively to helping the catching-up process of developing countries.*

The gains in profits seem to follow a similar trend though they are much mitigated.

On figures 4.3 and 4.4, the regression trees of the number of patents per firm for southern and northern firms show that the most important factor is the enforcement level in the country. With a strong enforcement more patents are filed. The threshold seems higher for northern firms than southern firms, as the technology is supposed to be more advanced, the potential losses from infringement are more important and therefore the level of protection required to incite more disclosure is higher.

We see that the breadth of patents plays a role too. With narrower patents, there are more patents filed by both northern and southern firms (figure 4.5). We note that after a certain level of patent breadth there does not seem to be any further decrease in patenting.

Finally we also observe that the variables "contract length" and "number of northern firms" play a role. This is reminiscent of the results found regarding the effect of these

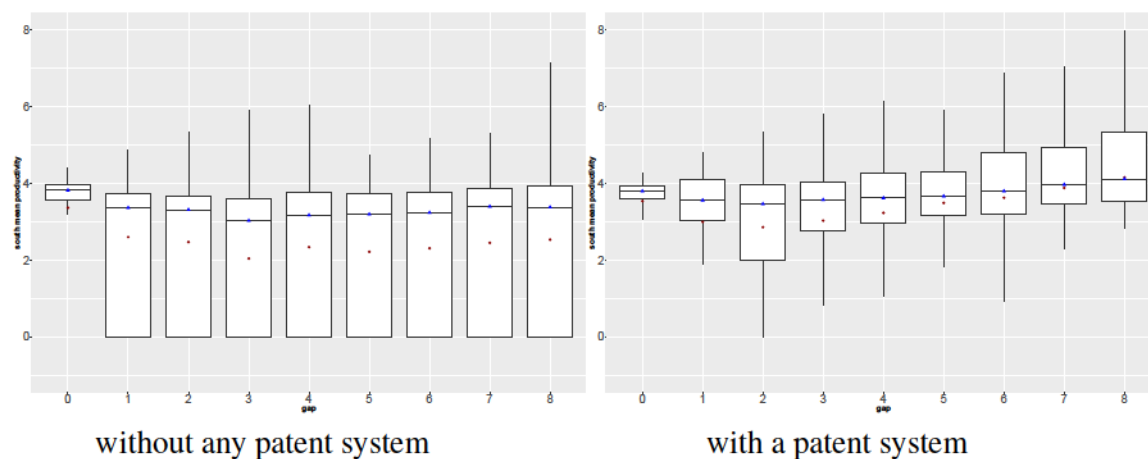


Figure 4.1: *Southern productivity according to gap, $t = 1000$*

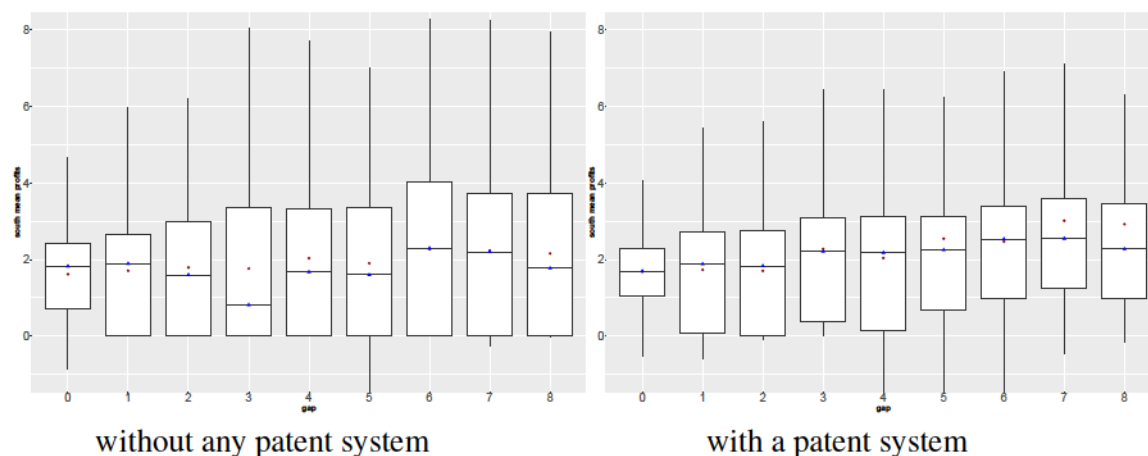


Figure 4.2: *Southern average profits according to gap, $t = 1000$*

variables on the performance of each part of the industry. We recall that having longer contracts is associated with a positive role on the industry performance through the training effects. Interestingly however is that number of northern firms plays a positive role for both patents from the North and from the South.

While the positive effect on northern firms is expected, and was interpreted as a competitive advantages over southern firms (see proposition 8, chapter 3). The effect on southern firms is a new result. We had previously found that increasing the number of northern firms would decrease the chances of survival of southern firms, the negative effect outweighed the benefits of having northern firms that transfer technologies. Here it appears that with more northern firms, southern firms are able to patent more innovations. Since innovation requires a good market performance, it would appear here that the effect of having technological transfers facilitated by innovation overcame the potential negative

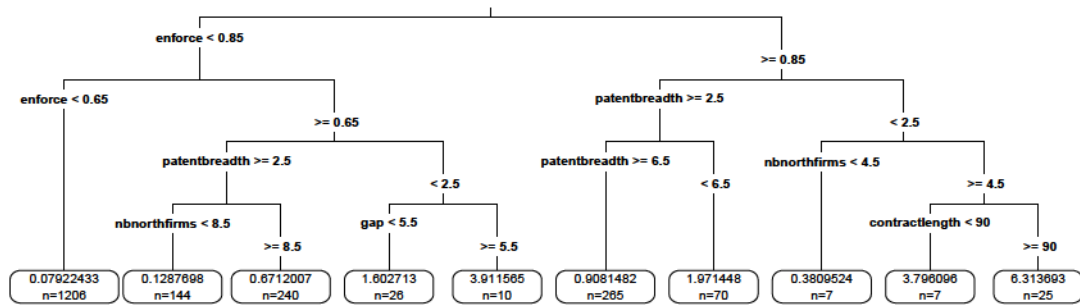


Figure 4.3: *Regression Tree showing the effect of different variables on the number of northern patents per northern firm*

impact on southern firms performance of an overwhelming presence of northern firms. This is also visible on the tree for southern firms' profits.

Proposition 4.24. *When northern firms disclose their technology, there are positive effects on the southern firms' innovation abilities facilitated by technological transfers.*

The main incentive for northern firms to patent thus appears to be a strong enforcement. Figure 4.6 presents the boxplots of the mean number of northern firms patents per different levels of enforcement. The results are unequivocally positive. As enforcement increases, the number of patents filed by the north strongly increases. Furthermore, for any level of enforcement below 0.5, the number of northern patents falls to (almost) 0. Basically this means that if enforcement is low (0.5 corresponds to a 50% chance of successfully infringing patents), northern firms will not be using the patent system and will revert to secrecy. The tree on figure 4.8 confirms this observation, and basically shows that there is an opposite effect of our explanatory variables on secrecy compared to what we observe for patents. This allows us to make a shortcut and assume that any level of enforcement below 0.5 is equivalent to there not being any IPR protection at all. The ratio of innovations kept secret to innovations patented in the North sharply decreases with the enforcement level (figure 4.7).

Proposition 4.25. *The stronger the enforcement of IPR in the developing country, the more the northern firms will be likely to disclose their technological advancements.*

The fact that northern firms disclose more technology means that the global knowledge stock increases, which is technically beneficial for the whole industry. Whether or not

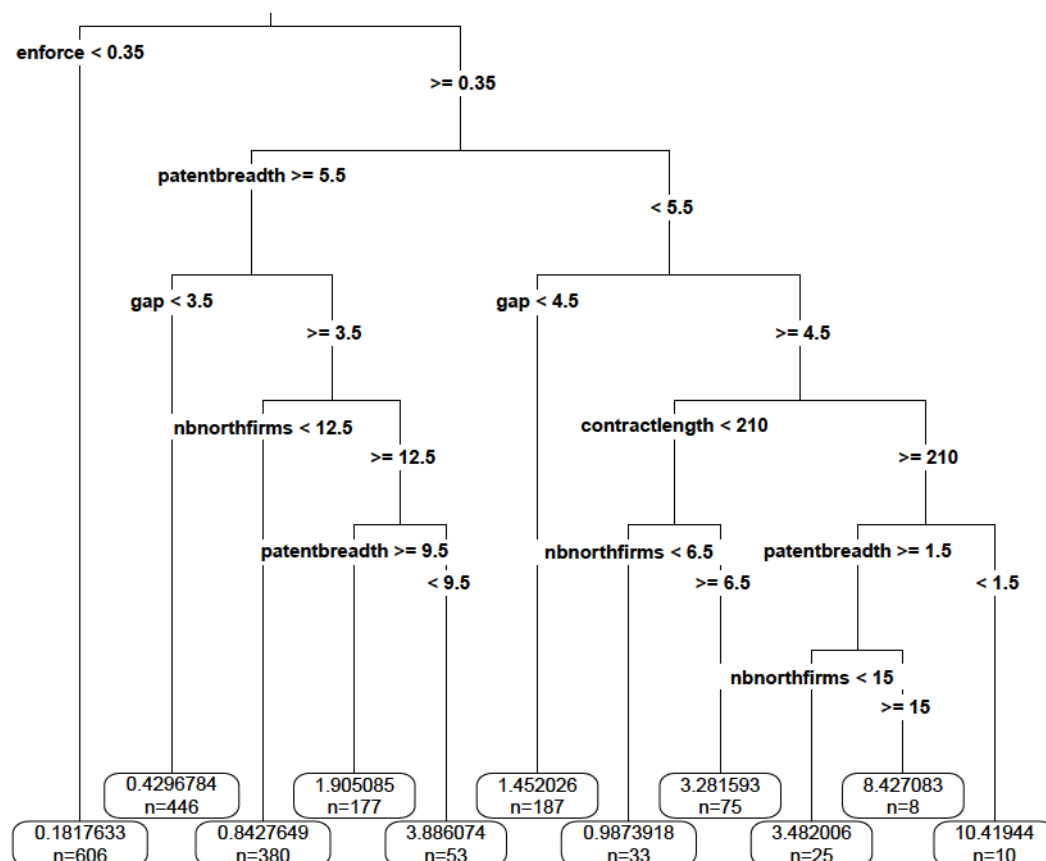


Figure 4.4: *Regression Tree showing the effect of different variables on the number of southern patents per southern firm*

this is interpreted as a good thing depends on which type of firms we consider. Southern firms will greatly benefit from this as radical technological changes will be facilitated, as well as innovation, whereas northern firms might be seeing from different eye the fact that southern firms are using, without any cost, technology created by northern firms so that they can become technological and (better armed) economic competitors.

We note however that while comparing the number of innovations patented and innovations kept secret that the the number of secret far exceeds the number of patents. Therefore although a patent system is in place, secrecy is still the most preferred option to protect a technology.

4.2.3 The consequences of a strongly enforced IPR system

A strongly enforced IPR system is thus desired by northern firms. Let us consider what happens when the level of protection is too strong. Looking at figure 4.9, which represents

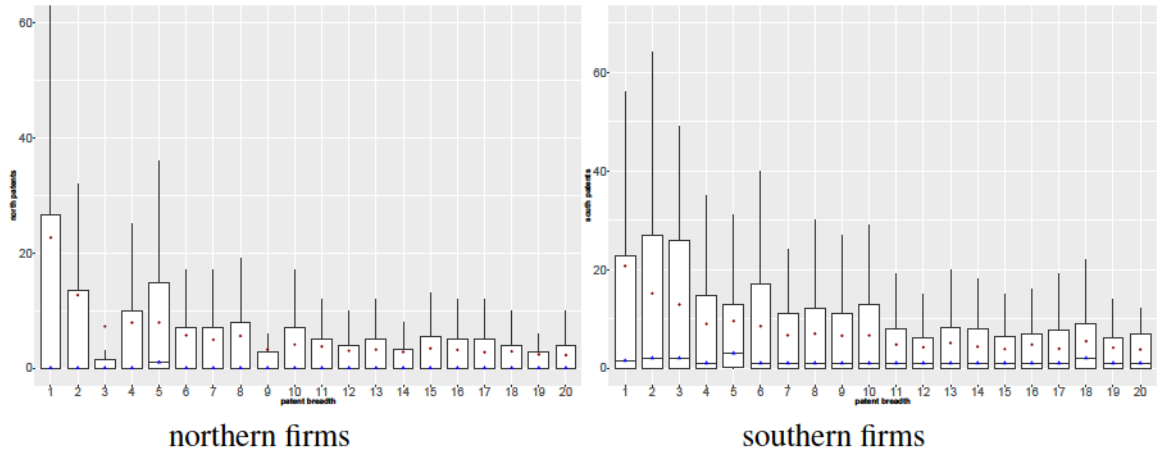


Figure 4.5: Mean number of patents per firm, per level of patent breadth $t = 1000$

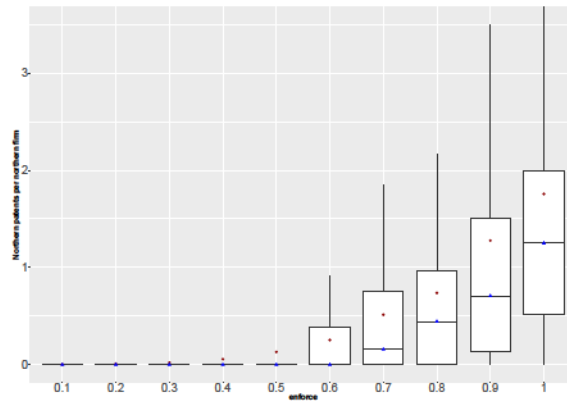


Figure 4.6: Number of northern patents at $t = 1000$, by level of enforcement

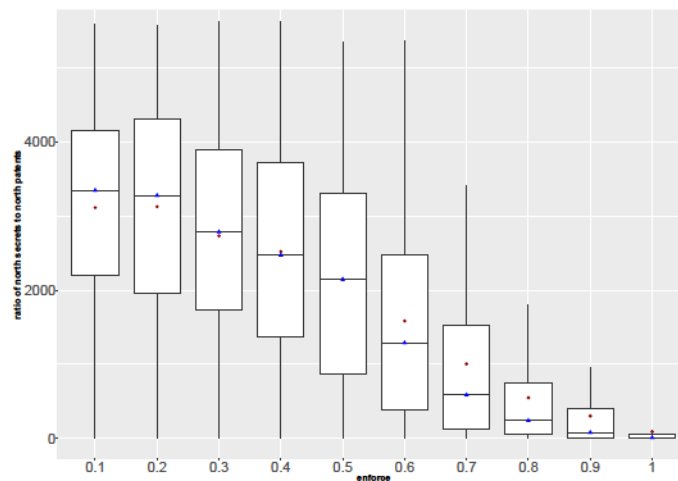


Figure 4.7: Ratio of innovations kept secret to innovations patented by the North, at $t = 1000$

the number of imitations per southern firms for different levels of enforcement, we can see two things.

First, as enforcement increases up to 0.9, the number of imitations steadily increases.

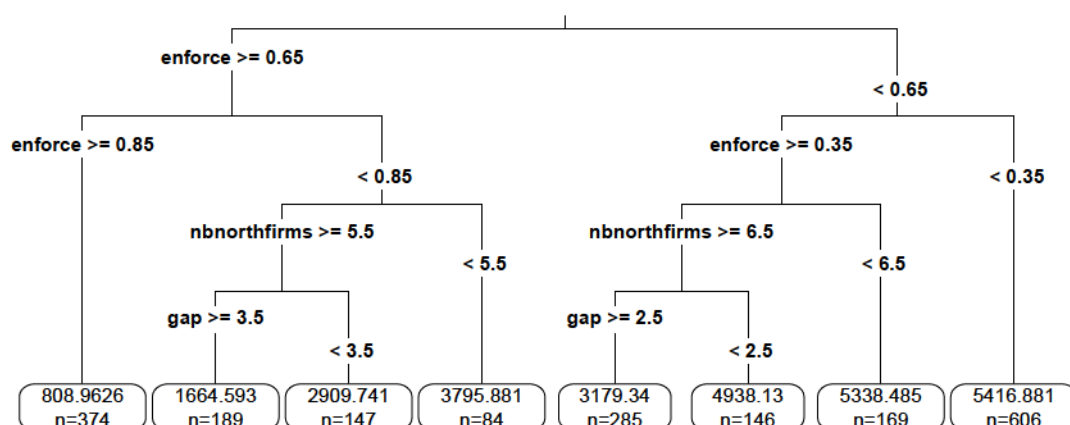


Figure 4.8: Regression Tree showing the effect of different variables on the total number of innovations kept secret at $t = 1000$

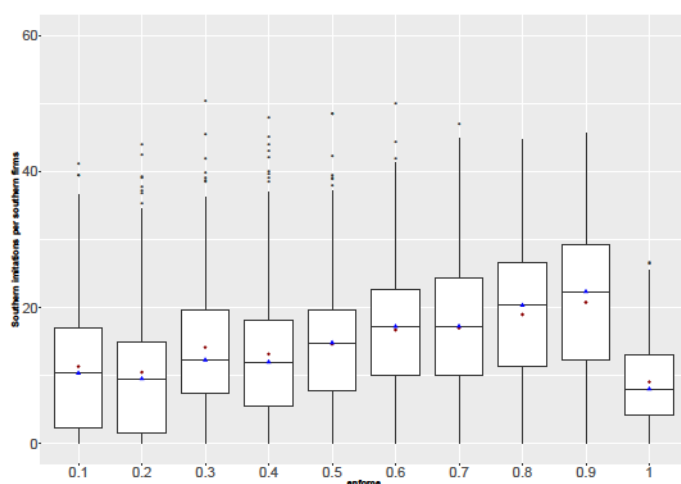


Figure 4.9: Number of imitations per southern firm, by enforcement levels

When the level is 1, that is perfect protection, the number of imitations by the South largely decreases. These effects can be explained by considering that an increase in enforcement there is more disclosure, which increases the opportunities for imitation; and up until 0.9, the effect of the increased opportunities outweighed the effect of the enforcement. Once we reached perfect enforcement, though the opportunity still increases (as seen on figure 4.6), the enforcement prevents most of the imitations on those patented technologies (up until patents expire). This implies that northern firms will prefer perfect protection, whereas this could potentially be detrimental for southern firms. How detrimental? First we know that those imitations are necessary for catching-up. Therefore, we can assume that with less imitations, the catching-up process is hindered. We can actually see this result on figure 4.10,

which plots the number of periods it takes to achieve catching-up for the subsample of runs where we did observe success in this endeavour. We can see that as the enforcement level increases, the time it takes to catch up decreases (due to imitations made possible by lower enforcement), however when perfect enforcement is in place, the catching up time increases back (though it is still lower than the case of very low enforcement).

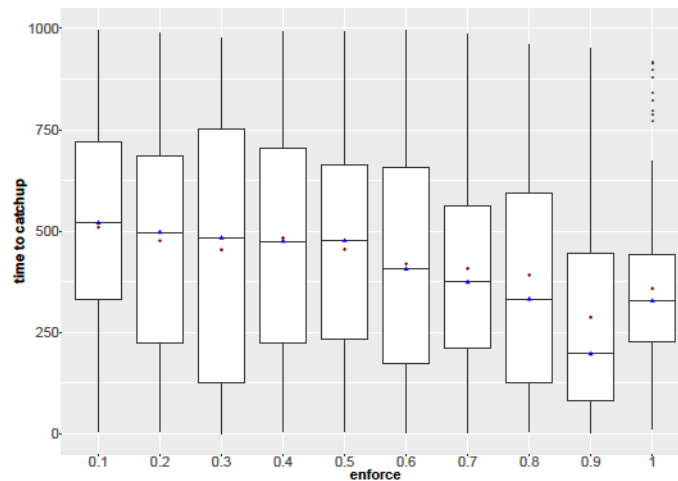


Figure 4.10: *Number of periods necessary to catch up, by enforcement levels*

Proposition 4.26. *As long as southern firms can imitate, their catching-up process will be sped up by the disclosure of technologies by the northern firms.*

Proposition 4.27. *A strongly enforced patent system will effectively block the imitations, despite the greater number of published innovations, thus negatively affecting the speed of catching-up.*

Another negative effect of a strong enforcement is seen through the loss of innovations incurred by southern firms. We can see that as enforcement increases, the knowledge created by southern firms also increases (figure 4.11), due to the gains in global knowledge thanks to the increased patents by northern firms. Furthermore, the total number of innovations made by southern firms also increases (adjusted per firm) (figure 4.12), which explains how the knowledge stock of southern firms increased in the first place. Where it gets unscrupulous is when we look at the usable innovations per southern firm. An innovation here is considered usable if it is not infringing on an active patent, which means that we are not even counting innovations that were infringing but the firm took their chances and were able to use it anyways despite the protection in place.

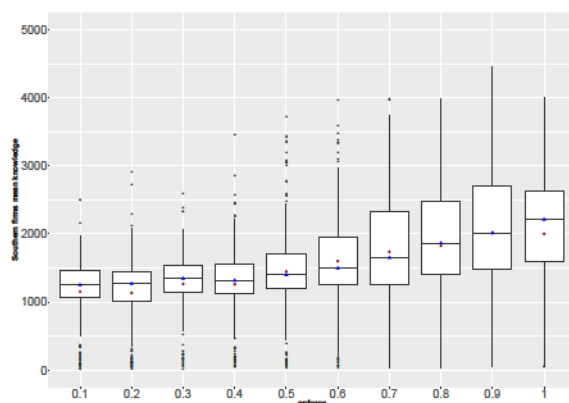


Figure 4.11: *Southern firms' mean knowledge stock at $t = 1000$, by enforcement level*

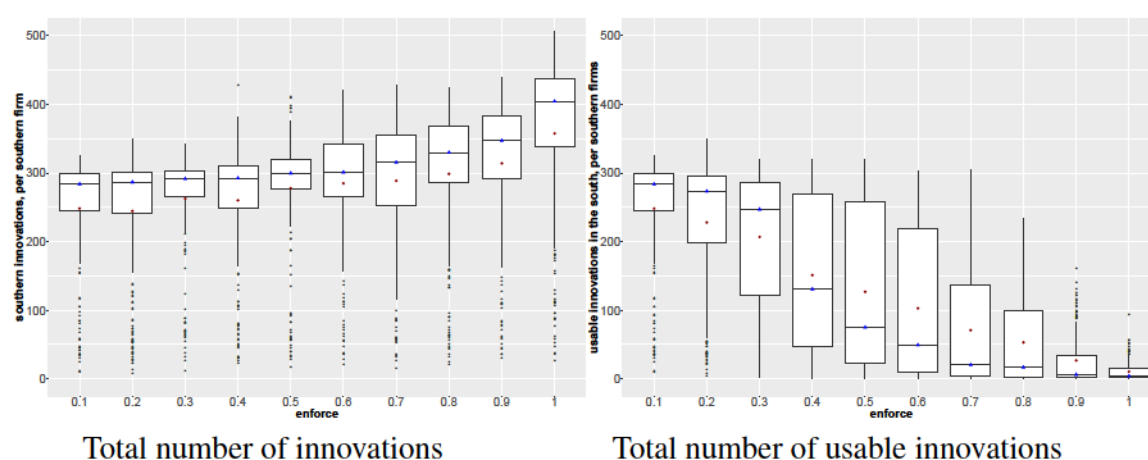


Figure 4.12: *Innovations by southern firms at $t = 1000$, by enforcement level*

We can see that the number of useable innovations decreases. This happens as we can see that patenting increases in both North and South with the level of enforcement. Southern firms end up not only blocking their peers but also considering that catching-up succeeds faster (unless there is perfect enforcement), when southern firms do reach the northern trajectory they end up experiencing more blockades. As a result there is a lot of technological development done by southern firms, which never comes to use.

Proposition 4.28. *An strongly enforced IPR system causes important losses for southern firms as the number of unusable innovations in the South increases.*

The unfortunate aspect of this proposition is that it implies that the South did manage to innovate as we have seen, and a strong IPR system prevented southern firms to use legitimately and, more importantly, costly to obtained technologies. This is reminiscent of what was observed in the literature regarding the "kicking away the ladder" effect. As we see that lax protection facilitates the use of those innovations and imitations that will allow

catching up, this implies that today's advanced economies went through a similar route. By imposing strong IPR they are preventing today's developing economies to do so.

Furthermore, we consider the strength of the patent protection through patent breadth. If we recall, with narrow patents, both southern and northern firms significantly increased their number of patents. We compare in figure 4.13 the mean profits of southern firms in the subsample of observations with narrow patents (less than 4) against observations with large patents. With high enforcement and narrow patents, it is also when we observe more patents from the North (figure 4.14). This tells us that the losses experienced by southern firms is all the more important with narrow patents. Indeed it appears that for innovation and technological disclosure narrow patents are preferable, because they create an opportunity for the South to catch up and further their development process, which they are able to achieve since they were successful at innovating. However they fail to reap the potential rewards of their innovation, at the technology space becomes crowded out with strongly enforceable patents.

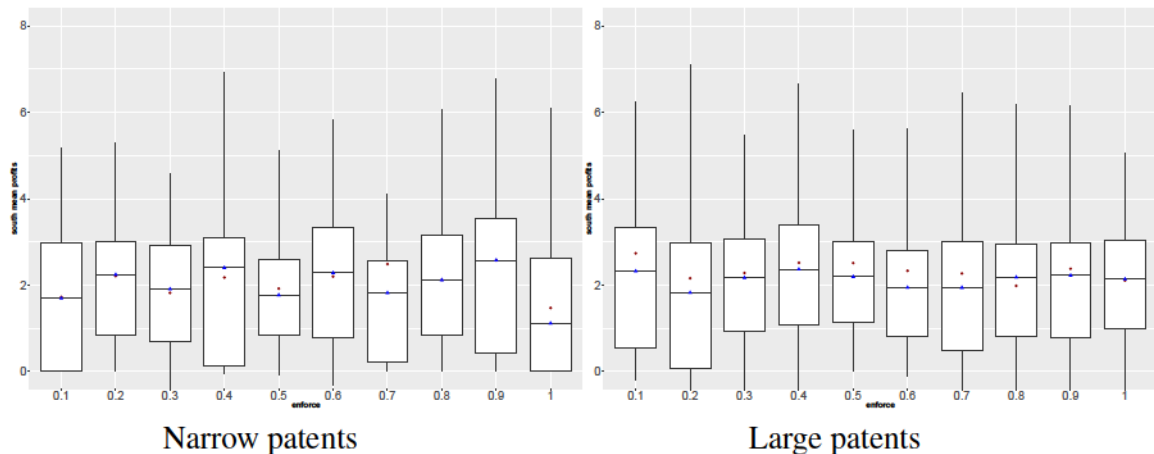


Figure 4.13: *Mean Profits of southern firms $t = 1000$, by enforcement level*

Proposition 4.29. *Narrow patents help significantly improve the southern firms' innovation abilities by increasing technological disclosure.*

An interesting observation that can be made here is that the economic benefit for northern firms of having perfect enforcement is low. Looking at figure 4.15, which plots the levels of profits (mean and max profits) reached by the northern firms according to different levels of enforcement. We see that the gain in mean profit is low. For the top performers (max profits) the impact is more pronounced. It shows that northern firms stand to gain economically from increased IPRs but also that this gain is not specifically so important.

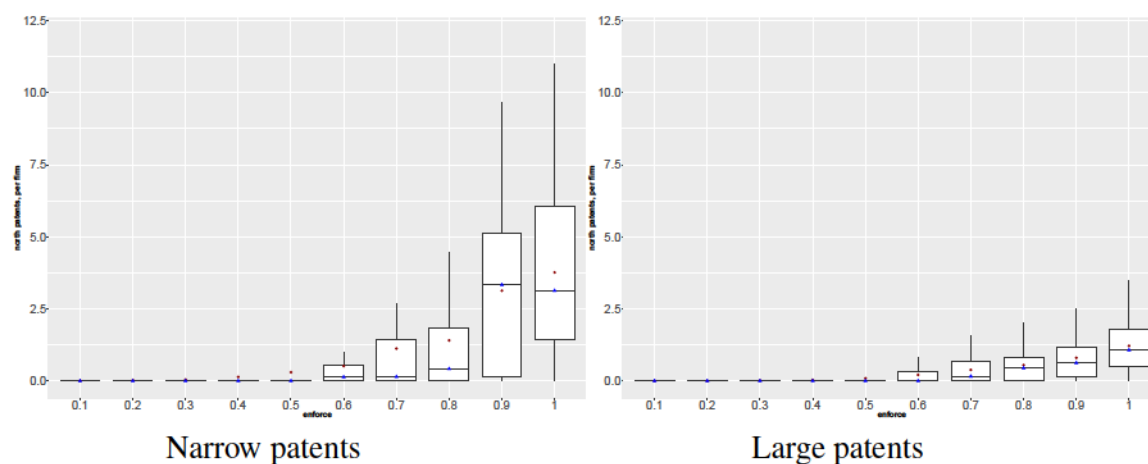


Figure 4.14: *number of north patents, per firm $t = 1000$, by enforcement level*

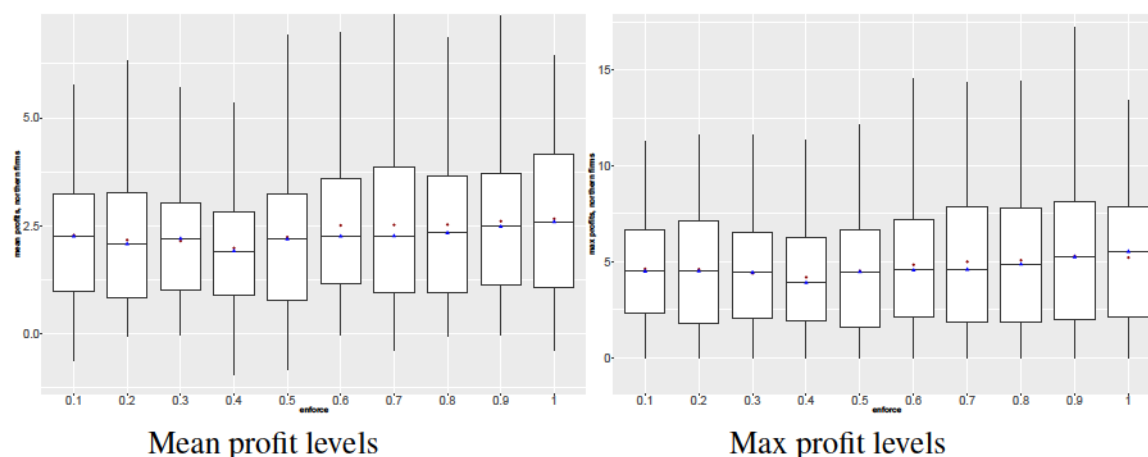


Figure 4.15: *Profits of northern firms at $t = 1000$, by enforcement level*

Even when we compare the case of narrow vs. large patents, profits for the north do not seem much affected (figure 4.16).

Proposition 4.30. *Northern firms do not experience important gains from an increased level of enforcement, suggesting that southern firms are not serious threats after all.*

The fact that developing economies need access to the knowledge and technology created by technologically advanced countries makes them even more vulnerable. Strongly enforced protection is desired by the North even if the economic benefits as we have seen are small. The benefits of a lax policy are even greater for southern countries. Therefore it should be socially preferable to help the development of those countries. Yet there is a strong imbalance of power in favour of developed countries exacerbated by the dependence of southern countries on attracting northern firms (we recall that without northern firms to interact with, southern firms failed to reach the advanced technological trajectory). It is

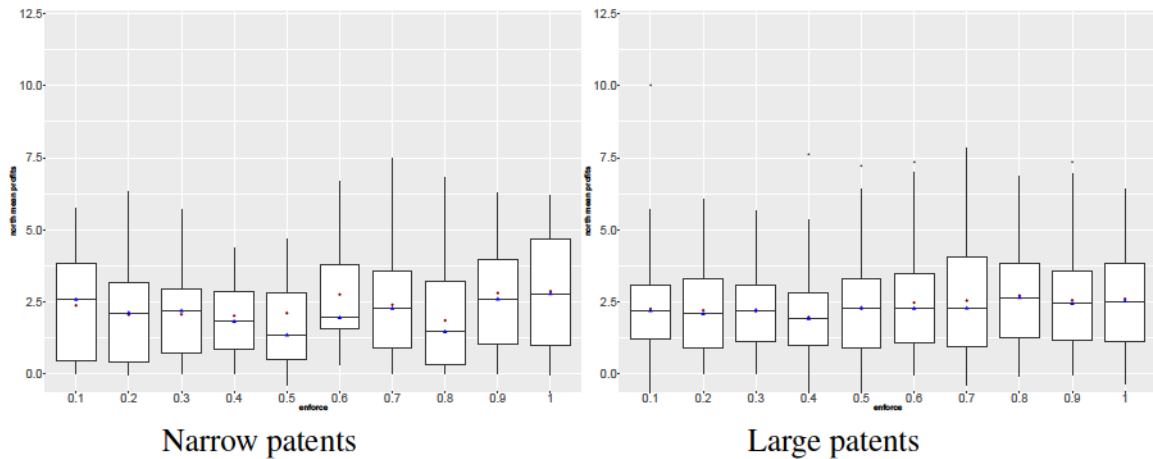


Figure 4.16: *Mean Profits of northern firms $t = 1000$, by enforcement level*

therefore obvious that the result will be what were observed during TRIPS negotiations, that is developed nations end up imposing their rule.

5 Conclusion

From our analysis, we can see that the technological development and the catching up process of southern firms benefits greatly from the disclosure of technologies from the northern firms. The problem is that northern firms do not have incentives to disclose their technologies if there is no protection against those disclosures. When there is an enforced patent system in place, the disclosure increases, and the imitations opportunities increase as long as the enforcement system is imperfect. The problem is that northern firms prefer a perfect enforcement situation, which as we have seen can impede the technological development of developing countries by hampering the innovation efforts of southern firms, on top of severely limiting the imitation prospects. Since developed countries have the upper hand in shaping international policy, developing countries will be incited to set up strong enforcement in order to comply with the rules, which will be detrimental to their own development.

By concluding that imitations are necessary and perfect protection is hindering the catching-up process unnecessarily, I am not advocating that a free pass should be granted to developing economies so that they can imitate without repercussion. First of all, this would not work, because then it kills the incentives for the sharing of knowledge. This brings the problem more on the side of the argument made by Cimoli et al. (2009), that

the problem is not so much how strong or how lax a protection system should be (in fact here we saw that the design of the patent system did not play such an important role as the policy variable did), but rather what shape should technology protection take. While we do make the case of narrow patents (which could be assimilated to utility patents), the problem still resides in the enforcement mechanisms that blocks innovation. Complying with patent rules may prevent illicit imitations but it also blocks southern firms who did manage to innovate, which can be source of important losses and can hinder the long term development of southern firms. A "better" IPR policy for developing countries should not be so restrictive on innovations.

Furthermore, given that minimum standards are imposed by TRIPS, and WIPO has for objective to further the worldwide standardisation of IPR policy, the strength of the patent system does not really matter, since every developing country will end up having the same one. And finally since we should be shifting away from patents, as they currently are, as development policy, it is not helpful in that setting to discuss the intricacies of the optimal patent system. As pointed at by Cimoli et al. (2011), apart from the pharmaceutical sector, patents are not usually a source of knowledge. While our model did represent patents as a source of knowledge, the findings in our analysis do not aim to contradict this view (as there is no alternative source of knowledge in the model, we cannot make a comparison). Instead, we focused on showing that technological disclosure is necessary for the development process. It does not have to happen through patents, for example the use of compulsory licensing would be effective in playing this disclosure role.

This reinforces the argument that if there were to be a renegotiation of IPR policies worldwide, they should be aimed at incentivizing advanced firms to share the knowledge with developing countries, unlike the current trend towards a more restrict agreement as the idea of a "TRIPS-plus". In emerging countries, the capacity to innovate and make their own technological advancement exists. The objective of a development policy should be to let them do so, as long as the consequences are not detrimental to northern firms.

Conclusion

Conclusion

This thesis aimed at contributing to the studies of the effects of intellectual property rights on the development and catching-up of developing countries. In order to answer this question, we had to gain a clear understanding of the role imitation and innovation play in technological progress. The first chapter highlighted the role of innovation and imitation at different stages of development, which helped us establish that "imitation", or technological transfers were necessary for the catching up process. It also gives further evidence of the need for countries to build their capabilities to enable catching up. I then investigated the channels and mechanisms behind those transfers and found that there was a rich set of possible mechanisms, with varying results, in play when it comes to North-South interactions. This helped build the analytical framework to first study the impact of a particular channel, that of local workers mobility, in a developing country on the catching up and development outcomes. The third chapter thus focused on building the North-South ABM. While building a basic model, I tested out many of the mechanisms present in model to see if FDIs from developed country could be conducive to technological transfers and help catching up. I find that this channel is indeed efficient, though mostly for developing countries that are not too far behind. The presence of northern firms in the local industry helps the catching up process, provided that northern firms do not have an overwhelming presence in the South. Furthermore, I find that a slightly rigid labour market forces firms to hold on to their workers longer, and thus enhances their gains from training. Technological transfers were thus more likely to happen under that type of setting.

With the basic workings of the model understood, I moved on to adding patents to this model to answer the main question that concerns the effect of TRIPS on developing countries. I found important effects that should be examined. First, when we consider that patents are incentives for developed economies to invest in the developing countries and share their technology, we find that they do succeed in diffusing knowledge and helping the

southern firms' develop and catch up. However, the northern firms's interest in technology disclosure increases with the enforcement of IPR in the developing country. As such, northern firms prefer perfect enforcement, which reduces the benefits for southern firms. Mainly they are not able to imitate anymore, but more importantly their own innovative efforts are severely hampered. Southern firms thus prefer narrow patents (as it allows for easier innovation) though in cases where the enforcement is slightly imperfect. The gains for northern firms are not that significant when it comes to perfect enforcement, they are thus not threatened by southern firms. This tells us that to help the catching-up process, IPR should aim at incentivising developed firms to disclose their knowledge and limit the blockage on southern innovation. This result is coherent with what happened in Korea when they were developing. The IPR policy was made up of utility patents and the IPR regime was not that rigid, which allowed for the development and catching up.

The North-South ABM is a contribution to the macroeconomic ABM that seek to study policy impacts and explore mechanisms underlying the interactions between North and South. The descriptive account of those interactions from chapter 2 tells us that there is a quite wide area of study that can be explored using the North-South ABM. I would particularly find it interesting to study the vertical spillover effects from FDI that may incur in the developing country. This would require modelling a intermediary sector and has the potential of enriching significantly the model, as the technology would also now have to develop in the new sector. This could imply a richer labour market with a more diverse set of workers' competencies. Opening up the South to international trade would help us also revisit classic questions of protectionism vs. openness for the developing economies as well as study trade transfer channels through both export and import could bring some interesting results regarding technological progress and the competition dynamics in an open economy. There is therefore quite a large potential to explore and refine this model, as well as finding results that could contribute to policy debates.

As the work of an economist, this thesis has mainly centred on the issue of economic growth and how can developing countries achieve it through technological development. The issue of the role international organisations should play in making development happen brought up in chapter 4 when discussing TRIPS raised the issue of multilateral international policy making. This game has lead to many policy choices imposed by powerful nations mainly safeguarding their interests over the common good.

Developed nations perceived developing countries as threats rather than potential partners in need of a leg up. The most concerning aspect of approaching the negotiations this way is that the consequences for each side are on different levels. For developed nations, protecting their interests mostly means their economic interest and the pursuit of technological progress that pushes the technological frontier (which is undeniably a necessity beyond economic motives). For developing countries, their development is at stake. Development, as we first presented it, is not just a question of improving the GDP, but also implies improving healthcare, education and living standards. Developing countries and, on a more concerning level, least developed countries are relying on their economic development to ward off ever increasing inequalities and spiralling extreme poverty. It appears that too often, these outcomes are left out, or as we have seen with the TRIPS example, swept under the rug of non binding obligations.

However, it is not a novel idea that helping developing nations progress can be compatible with the economic interest of developed nations, which in turn enables the advancement of society in part through technology.

Developing countries have the growing market, the labour force, the will to improve skills and the dormant capabilities to learn and drive technological progress. We have seen it happen with Asian Tigers; and emerging countries such as China and India are demonstrating their potential with every bit of technological progress.

Therefore, in the long term, it is apparent that there is to gain from helping developing nations in their development process. The questions and perspectives for future research thus brought out concerns reviewing the heavily unbalanced multilateral negotiation process that takes place at international organisations that lead to unfair policies. One of the potential remedy to that situation would be to prove that there are gains from actual help that benefit developed countries, and thus investigating potential development policies that do succeed in bringing sustainable development while not impeding advanced countries' interest and cultivate their thirst for technological progress.

Appendices

Appendix **A**

Estimation of the model

1 Linear Specification

We first started with the linear regressions, estimated through simple OLS techniques, the results are presented in table 2. The model estimated is $timeg = \beta_0 + \beta_1 pub + \beta_2 G_0 + \beta_3 edu1 + \beta_4 edu2 + \beta_5 infra$. Basically we just linearized all the parameters and estimated different model specifications by including or removing some of the explaining variables. We used here publications as the variable for exogenous research. The explanatory powers are limited (small R^2). We find in those estimations, contrary to the original analysis that the secondary education variable is most significant for the linear case. This is here explained by the greater variance of this variable (see table 4 in the appendix). It would seem that in this sample countries are more homogenous regarding primary education level.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	timeg	timeg	timeg	timeg	timeg	timeg	timeg
pub	0.041	-0.122	-0.199	0.061	0.014	-0.129	0.042
g0		-0.255*	-0.392 **	-0.767 ***	-0.804 ***	-0.470 **	-0.833 ***
edu1			-0.258 *		-0.124	-0.272 **	-0.133
edu2				-0.823 ***	-0.777 ***		-0.766 ***
infra						-0.173	-0.077
<i>N</i>	111	111	111	111	111	111	111
R^2	0.0017	0.0400	0.0954	0.3021	0.3141	0.1077	0.3166

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A.1: *Estimations for linear model*

Development theory would at first suggest that primary education should be a better discriminant in technological levels difference. There are a lot of developing economies in that sample, countries for which low-skilled human capital is more important to their development (see also Vandebussche et al., 2006). Having secondary education as the most significant one here would suggest that there has been a shift from the first period studied to this one in terms of what constitutes the minimum level of skilled required in the workforce, thus indicating a general increase in the technological level across the globe. In those linear estimations, when significant, the sign of the coefficient relating to G_0 is as expected negative, the same can be said about the education variables. This helps inferring that those variables which relate to the imitation capability have a positive effect on countries' catching up process.

Because of the ambiguity implied by the assumptions on the effect of the initial gap (seen through the confrontation of actual vs. potential spillovers) on the time derivative, the linear model cannot capture the dual effects the initial gap has on the speed of growth of the gap, in fact we should expect the coefficient of G_0 to be insignificant, if not, then it seems to suggest one effect on average outperforms the other. We have checked for quadratic effects of the initial gap, under the hypothesis that the effect is not solely linear. In light of what has been previously discussed, one should expect the sign of the quadratic coefficient to be positive, suggesting that at first the effect of the initial gap benefits a catching up process, though if the initial gap is too high, then countries have much more difficulty keeping up and drift away, thus falling behind. When estimated, those effects were found to be not significant, and the sign changes according to which variables are included, thus indicating a low explaining power of this type of model.

Finally, we find that our chosen exogenous research variable (publications) does not perform very well in the linear case. It is generally not significant and the signs are not as expected. This is not very surprising given the poor correlation with the dependent variable, the results of a linear estimation were likely to be rather limited. We do not conduct further testing on those regressions, as we know already of the limitations of our sample, and acknowledge that this specification is not retainable anyways.

2 Non Linear regressions

The technique applied to run the non-linear regression used the “plinear” algorithm in the R package [nls2]. This provided an estimation using least squares for the nonlinear specifications. We note that the Gauss-Newton algorithm was also used, and yielded similar results once correct initial values were found. It in fact because we could not have a precise idea that the “plinear” algorithm was useful. Basically, the linear part of the equation is estimated with normal OLS methods, which only leaves the non linear parameters to evaluate. This way, only starting values for non-linear parameters had to be specified, which for the final model meant only two values instead of five. The only non-linear coefficients were those of policy parameters. The starting values chosen were of order of Verspagen’s results. Overall the least squares algorithms to estimate nonlinear coefficients is based on the same principle. Given initial values, the fitted equation is computed and residuals are computed. The algorithm then consists in devising other coefficients which will reduce the sum of squares of the residuals, and it will keep refining the estimation until a desired level of accuracy is attained and/or a max number of iteration has been reached.

The plinear algorithm in R is based on the Golub-Pereyra algorithm¹. The advantage of such method is that only coefficients which are not linear have to be specified a starting value, thus reducing the search for starting values which will make the optimization algorithm converge.

Basically, since our model is (*PAT* or *PUB* depending on the specification chosen): $gapgrowth_i = \beta_0 + \beta_1 PAT + \beta_2 G_0 \exp(\frac{G_0}{d_1 edu + d_2 infra})$, the linear coefficients here are β_0 , β_1 and β_2 . We only have to specify starting values for d_1 and d_2 .

The algorithm consist in separating the nonlinear part from their linear coefficients, here $G_0 \exp(\frac{G_0}{d_1 edu + d_2 infra})$, and optimizing for d_1 and d_2 .

To take the notation of the original paper, our vector \mathbf{a} is $(\beta_0, \beta_1, \beta_2)$, α is (d_1, d_2) and the matrix $\{\Phi(\alpha)\}_{i,j} = \phi_j(\alpha; t_i)$ translates here into: i refers to the observations (131), j refers to the linear component (here there are 3). so $\{\Phi(\alpha)\}_{i,j} = (1, PAT, G_0 \exp(\frac{G_0}{\alpha.(edu,infra)}))^T$.

2

¹for more detailed maths refer to Golub, Gene H., and Victor Pereyra. ”The differentiation of pseudo-inverses and nonlinear least squares problems whose variables separate.” SIAM Journal on numerical analysis 10.2 (1973): 413-432.

²The R code thus used was
`startlist j- list(d1=-0.4, d3=-9)`

- Initial values for the plinear algorithm (final specification): $d1 = -0.4, d3 = -9$
- Initial values for the Gauss-Newton algorithm (final specification): $\beta_0 = 0.1, \beta_1 = -0.05, \beta_2 = -0.03, d1 = -0.08, d3 = -5$

```
controlparameters j- nls.control(maxiter = 10000, minFactor = 0.0000001, printEval=T, warnOnly=T)
algo j- "plinear"
nlreg4j-nls2(TimeG~cbind(1,PAT,G0*(exp(G0/(d1*edu1+d3*Infra))))), data=moogle, start=startlist,
control=controlparameters, algorithm=algo) summary(nlreg4)
```

Appendix **B**

Analytical computations

The model retained is : $timeG = \beta_0 + \beta_1 PUB + \beta_2 G_0 \exp(\frac{G_0}{d_1 edu + d_2 infra})$

where $\beta_1, \beta_2, d_1, d_2 < 0$

1 Marginal effects on the speed of growth of the gap

The marginal effects of the initial gap (G_0) on the speed of growth of the gap :

$$\begin{aligned} \frac{dtimeG}{dG_0} &= \beta_2 \exp(\frac{G_0}{d_1 edu + d_2 infra}) + \beta_2 G_0 \exp(\frac{G_0}{d_1 edu + d_2 infra}) * \frac{1}{d_1 edu + d_2 infra} \\ &= \beta_2 \exp(\frac{G_0}{d_1 edu + d_2 infra}) (1 + \frac{G_0}{d_1 edu + d_2 infra}) \end{aligned}$$

- $\beta_2 \exp(\frac{G_0}{d_1 edu + d_2 infra}) (1 + \frac{G_0}{d_1 edu + d_2 infra}) > 0$ for $G_0 > -(d_1 edu + d_2 infra)$

- $\beta_2 \exp(\frac{G_0}{d_1 edu + d_2 infra}) (1 + \frac{G_0}{d_1 edu + d_2 infra}) < 0$ for $G_0 < -(d_1 edu + d_2 infra)$

– which contains the case where $G_0 < 0$

The marginal effect of policy variables (for example edu) on the speed of growth of the gap:

$$\begin{aligned} \frac{dtimeG}{dedu} &= \beta_2 G_0 \exp(\frac{G_0}{d_1 edu + d_2 infra}) * (\frac{-G_0 * d_1}{(d_1 edu + d_2 infra)^2}) \\ &= -\beta_2 d_1 (\frac{G_0}{d_1 edu + d_2 infra})^2 \exp(\frac{G_0}{d_1 edu + d_2 infra}) \\ \frac{dtimeG}{dedu} &< 0 \text{ for any } G_0, \text{ edu or infra.} \end{aligned}$$

2 Marginal effects on the learning capability

- Effect of a given policy variable (here edu): $\frac{d \exp(\frac{G_0}{d_1 edu + d_2 infra})}{dedu} = (\frac{-G_0 * d_1}{(d_1 edu + d_2 infra)^2}) * \exp(\frac{G_0}{d_1 edu + d_2 infra})$
 - > 0 for $G_0 > 0$
 - < 0 for $G_0 < 0$
- Effect of the initial gap: $\frac{d \exp(\frac{G_0}{d_1 edu + d_2 infra})}{dG_0} = \exp(\frac{G_0}{d_1 edu + d_2 infra}) * \frac{1}{d_1 edu + d_2 infra} < 0$

Appendix **C**

Sample of countries

ISO3 code	Country	timeG	Initial Gap	Start Year	Root 1
AGO	Angola	-0.02	2.68	1985	N/A
ALB	Albania	-0.01	2.07	1985	1.20
ARE	United Arab Emirates	0.01	-0.70	1986	1.03
ARG	Argentina	-0.00	1.40	1985	1.06
AUS	Australia	-0.01	0.16	1985	0.11
AUT	Austria	-0.00	0.16	1985	0.47
AZE	Azerbaijan	-0.08	3.70	1993	1.13
BEL	Belgium	-0.00	0.26	1985	0.38
BEN	Benin	0.01	3.28	1985	N/A
BGD	Bangladesh	-0.01	3.71	1985	N/A
BGR	Bulgaria	0.00	1.51	1985	0.94
BHR	Bahrain	0.00	0.43	1985	1.01
BOL	Bolivia	0.00	2.37	1985	1.46
BRA	Brazil	0.01	1.53	1985	1.12
BRN	Brunei Darussalam	0.02	-0.73	1985	1.05
BWA	Botswana	-0.02	1.90	1985	1.37
CAN	Canada	0.00	0.11	1985	0.03
CHE	Switzerland	0.01	-0.10	1985	-0.29
CHL	Chile	-0.03	1.90	1985	1.04
CHN	China	-0.06	3.38	1985	1.18
CIV	Cote d'Ivoire	0.03	2.89	1985	N/A
CMR	Cameroon	0.02	2.46	1985	1.94
COD	Congo, Dem. Rep.	0.07	3.77	1985	N/A
COG	Congo, Rep.	0.02	2.38	1985	2.18
COL	Colombia	0.00	1.74	1985	1.23
CRI	Costa Rica	-0.00	1.39	1985	1.16
CYP	Cyprus	-0.00	0.97	1985	1.03
CZE	Czech Republic	-0.01	0.93	1990	0.75
DEU	Germany	0.00	0.21	1985	0.45
DNK	Denmark	0.00	0.15	1985	-0.04
DOM	Dominican Republic	-0.02	1.84	1985	1.28
DZA	Algeria	0.01	1.68	1985	1.29
ECU	Ecuador	0.01	1.79	1985	1.28
EGY	Egypt, Arab Rep.	-0.02	2.63	1985	1.21
ERI	Eritrea	0.03	3.45	1992	N/A
ESP	Spain	-0.01	0.56	1985	0.68
EST	Estonia	-0.03	1.67	1990	0.85
ETH	Ethiopia	0.00	4.22	1985	N/A
FIN	Finland	-0.00	0.29	1985	0.01

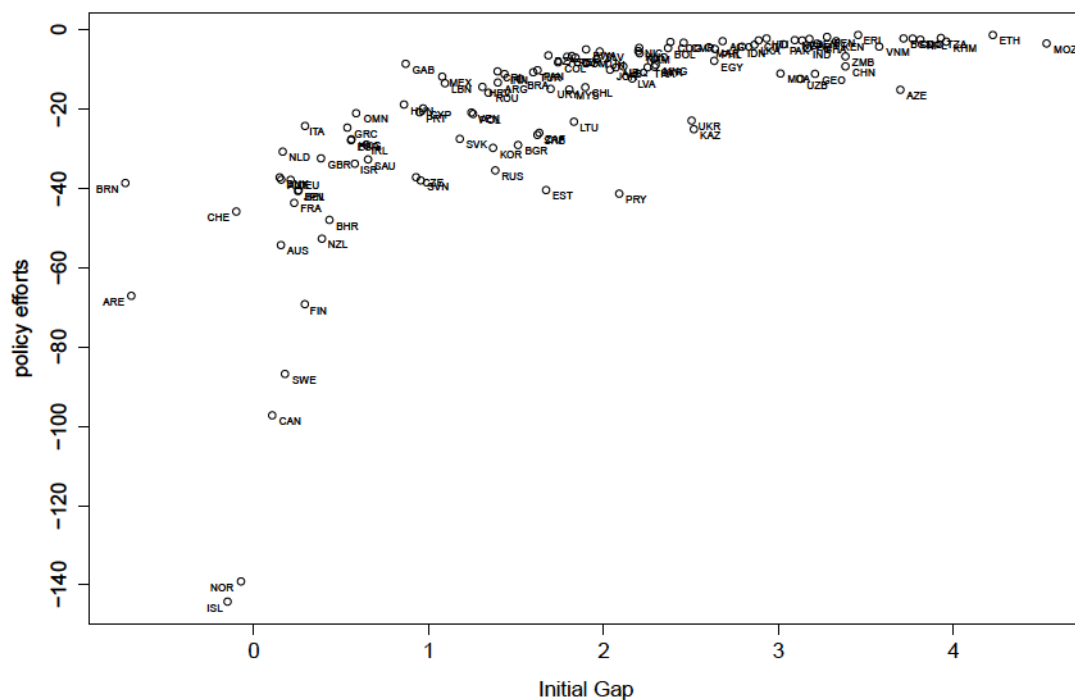
FRA	France	0.00	0.23	1985	0.47
GAB	Gabon	0.02	0.87	1985	1.20
GBR	United Kingdom	-0.01	0.39	1985	0.10
GEO	Georgia	-0.04	3.21	1993	1.15
GHA	Ghana	-0.00	3.22	1985	1.78
GRC	Greece	-0.00	0.54	1985	0.75
HKG	Hong Kong SAR, China	-0.01	0.56	1985	1.04
HND	Honduras	0.01	2.20	1985	1.38
HRV	Croatia	-0.01	1.31	1990	0.97
HTI	Haiti	0.02	2.93	1985	N/A
HUN	Hungary	0.00	0.86	1985	0.83
IDN	Indonesia	-0.01	2.79	1985	1.53
IND	India	-0.02	3.16	1985	1.43
IRL	Ireland	-0.03	0.64	1985	0.59
IRN	Iran, Islamic Rep.	-0.00	1.43	1985	1.15
IRQ	Iraq	0.00	2.11	1985	1.21
ISL	Iceland	0.01	-0.15	1985	0.37
ISR	Israel	-0.00	0.58	1985	-0.30
ITA	Italy	0.01	0.29	1985	0.66
JOR	Jordan	0.01	2.04	1985	1.12
JPN	Japan	0.01	0.25	1985	0.58
KAZ	Kazakhstan	-0.05	2.52	1993	1.10
KEN	Kenya	0.02	3.33	1985	N/A
KHM	Cambodia	-0.03	3.96	1985	2.48
KOR	Korea, Rep.	-0.03	1.37	1985	0.87
LBN	Lebanon	-0.00	1.09	1985	1.11
LKA	Sri Lanka	-0.02	2.86	1985	1.64
LTU	Lithuania	-0.03	1.83	1993	1.03
LVA	Latvia	-0.04	2.16	1993	1.10
MAR	Morocco	-0.00	2.60	1985	1.48
MDA	Moldova	-0.00	3.01	1992	1.16
MEX	Mexico	0.00	1.08	1985	1.13
MNG	Mongolia	0.01	2.30	1985	1.21
MOZ	Mozambique	-0.02	4.53	1985	1.81
MYS	Malaysia	-0.02	1.80	1985	1.12
NAM	Namibia	0.00	2.21	1985	1.32
NGA	Nigeria	-0.00	3.09	1985	N/A
NIC	Nicaragua	0.02	2.20	1985	1.47
NLD	Netherlands	-0.00	0.17	1985	0.09
NOR	Norway	-0.01	-0.07	1985	0.17
NPL	Nepal	-0.00	3.81	1985	N/A
NZL	New Zealand	-0.00	0.39	1985	0.16
OMN	Oman	-0.00	0.59	1985	1.08
PAK	Pakistan	-0.00	3.03	1985	1.69
PAN	Panama	-0.01	1.62	1985	1.17
PER	Peru	0.00	1.82	1985	1.29
PHL	Philippines	0.00	2.64	1985	1.43
POL	Poland	-0.01	1.25	1985	0.92

PRT	Portugal	-0.00	0.95	1985	0.89
PRY	Paraguay	0.02	2.09	1985	1.09
ROU	Romania	0.00	1.34	1985	1.09
RUS	Russian Federation	-0.01	1.38	1990	0.99
SAU	Saudi Arabia	0.01	0.65	1986	1.06
SEN	Senegal	0.01	3.18	1985	N/A
SLV	El Salvador	-0.00	1.98	1985	1.37
SRB	Serbia	0.01	1.62	1990	1.08
SVK	Slovak Republic	-0.01	1.18	1987	0.93
SVN	Slovenia	-0.02	0.95	1990	0.71
SWE	Sweden	0.00	0.18	1985	-0.28
SYR	Syrian Arab Republic	0.00	2.29	1985	1.21
THA	Thailand	-0.02	2.25	1985	1.19
TUN	Tunisia	-0.00	1.96	1985	1.20
TUR	Turkey	-0.01	1.60	1985	1.11
TZA	Tanzania	-0.01	3.93	1985	N/A
UKR	Ukraine	-0.03	2.50	1993	1.07
URY	Uruguay	-0.01	1.70	1985	1.09
UZB	Uzbekistan	-0.00	3.13	1990	1.16
VEN	Venezuela, RB	0.01	1.24	1985	1.09
VNM	Vietnam	-0.03	3.58	1985	1.53
YEM	Yemen, Rep.	-0.01	3.13	1989	N/A
ZAF	South Africa	0.00	1.63	1985	1.03
ZMB	Zambia	0.00	3.38	1985	1.28

Appendix **D**

Additional plots for the analysis on catching up

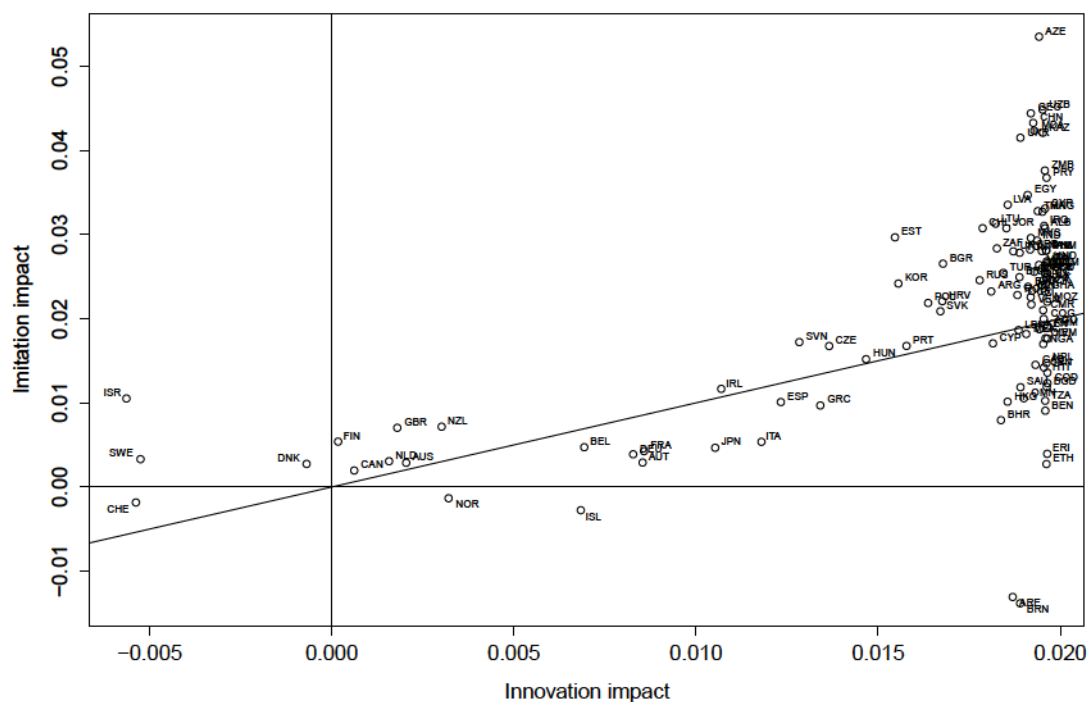
1 Policy efforts against the initial gap



In this plot, the smaller the value of the policy efforts, the better (the policy coefficients are estimated to be rightfully negative).

We note that Norway and Iceland score particularly high, and that Brunei and the UAE do not seem to fare so well with regards to what could be expected from their initial gap, thus confirming the expected end results.

2 Innovation against imitation effect on speed of growth of the gap



Note: the imitation effect is given as $-\beta_2 G_0 \exp\left(\frac{G_0}{d_1 \text{edu} + d_2 \text{infra}}\right)$ for clearer reading (as in figure 1). The plot should be read as for example:

- Canada is situated above the 45° angle line, therefore, its imitation effect is stronger than its innovation effect, the speed of growth of the gap is therefore negative as the decrease of the speed due to imitation is larger than the increase of the speed due to innovation.
- For Switzerland, the speed of the growth of the gap increases due to imitation by the US, but reduces more due to its strong innovation performance, the net effect is therefore a decrease of the growth of the gap, thus improving its lead.
- Israel, Sweden and Denmark benefit from both innovation and imitation as both impacts on the speed of growth of the gap are negative.

- As France is under the 45° angle line, the decrease of growth of the gap due to imitation is not sufficient to outweigh the increase of the gap due to innovation by the leader, as a result, its net effect is an increase of the gap.

Appendix **E**

The min function with decreasing returns

The model uses a particular production technology:

$$Q_i = A_i * \min(L_i, \alpha K_i)^\beta \text{ with } 0 < \beta < 1 \quad (\text{E.1})$$

This complication serves two purposes, the *min* function as we know represents perfect complements and the use of the β parameter represents a form of decreasing returns to scale.

In the context of this model, the perfectly complementary factors serves to represent the scale limitations of the capital equipment. If the firm only has three machines, then no matter how many extra employees the firm hires, production will always be limited by the number of machines available. Similarly, if the firm only has two employees and each machine requires two people to operate it, then no matter how many machines the firm adds, it will not be able to increase production. There is no substitute to either factor. A simple Leontief production function cannot capture the decreasing returns aspect of production which might cause scale issues in the model: given the correct market environment, firms might be incited to increase production in rather large amounts thus generating an explosion in supply which will cause prices to fall very close to zero and the model would not function. More importantly decreasing returns to scale also serve to add realism to firms' behaviour. Though increasing capacity leads to increasing production, some managerial issues also increase with the scale of a firm. Labour force is made of humans which are prone to mistakes. Machines are subject to failure as well. Management costs increase as well. Adding failure rates to the model would add some unnecessary

disturbances. The use of decreasing returns allow to account for these extra effects which do affect firms' decisions.

In the structure of the model, decisions like capital investment and hiring workers (or firing them) are important to firms' development. As I explained in the model, the decision to invest in capital is anchored in simple profit maximising behaviour. Below is the a more extensive explanation of the behaviour of the chosen specification.

We note that in this appendix we consider the more complicated case of the production function with capital costs, which are essentially sunk costs as capital units must be paid for regardless of whether or not they'll be used. In the model, we chose to forego these costs to simplify the decision processes.

1 Planning desired capital and labour in the long term

As basic microeconomics would have it, the long term for a firm implies that it has controls over every production factor. Thus we here consider that capital and labour are flexible variables. In the model, firms chose their desired level of capital to set their investment for the next period. At the next period, they chose the labour force which will match their capital decision. In essence and theoretically firms do have the possibility to control all their inputs, which is why they first seek to improve the complete production process (capital and labour).

For the following demonstration we will imply that variables are at the expected value (i.e. $p^e = p$, $\pi^e = \pi..$) and remove the temporal and firm indices t and i . The cost of labour is w and the cost of capital is c . As in the model, every factor generates a cost even if they are not used in production.

Profit is given by the following:

$$\pi = A * \min(L, \alpha K)^\beta * p - wL - cK \quad (\text{E.2})$$

with $0 < \beta < 1$ and $\alpha, p, w, c > 0$

Because of decreasing returns to scale, this function can be maximised, by verifying

two first order conditions $\frac{\delta\pi}{\delta L} = 0$ and $\frac{\delta\pi}{\delta K} = 0$

$$\frac{\delta\pi}{\delta L} = \begin{cases} \beta ApL^{(\beta-1)} - w & \text{if } L \leq \alpha K \\ -w & \text{if } L > \alpha K \end{cases} \quad (\text{E.3})$$

$$\frac{\delta\pi}{\delta K} = \begin{cases} \alpha\beta Ap(\alpha K)^{(\beta-1)} - c & \text{if } L \geq \alpha K \\ -c & \text{if } L < \alpha K \end{cases} \quad (\text{E.4})$$

Since $w \neq 0$ and $c \neq 0$, we know that if $L > \alpha K$ or $L < \alpha K$ then at least one of the FOCs will not be verified, therefore the profit will never be maximised in those cases. Economically, this makes sense because if there is an imbalance in production factors, then some end up being not utilised to produce anything while still costing something which cannot be offset by a revenue. Therefore, having too much (or too little) of one factor constitutes a set loss for the firm.

This thus tells us that profit may only be maximised if $L = \alpha K$.

Therefore the profit maximisation problem becomes :

$$\begin{cases} \max_{L,K} \pi = A * \min(L, \alpha K)^\beta * p - wL - cK \\ \text{stc} : L = \alpha K \end{cases} \quad (\text{E.5})$$

Solving this by incorporating the constraint gives us:

$$\max_L \pi = A * L^\beta * p - wL - \frac{c}{\alpha}L$$

Setting the sufficient FOC $\frac{\delta\pi}{\delta L} = 0$ gives us

$$\frac{\delta\pi}{\delta L} = \beta ApL^{(\beta-1)} - w - \frac{c}{\alpha} = 0$$

we thus find the optimal level of labour L^* and capital K^* since $L = \alpha K$

$$\begin{cases} L^* = \left(\frac{\alpha w + c}{\alpha A \beta p}\right)^{\frac{1}{\beta-1}} \\ K^* = \frac{1}{\alpha} \left(\frac{\alpha w + c}{\alpha A \beta p}\right)^{\frac{1}{\beta-1}} \end{cases} \quad (\text{E.6})$$

Therefore, if the firm has control over both inputs, it has to choose K^* and subsequently L^* . And like in a normal Leontief function, this optimal combination is in the corner of the isoquant curves, thus including the necessary condition that $L = \alpha K$.

2 The short term: adjusting labour to the current capital stock

Above we discussed the case where both factors were adjustable, and showed the existence of a best combination. Though in our model, capital and labour are indeed flexible, there are circumstances which may restrict this flexibility. This pertains more specifically to capital. Two constraints exist in this model :

- Capital may not be resold. This prevents firms from decreasing the level of capital to adjust to a lower (potentially optimal) level.
- Capital investment may be costly and have low returns to investment. This means that firms may not be able to increase their level of capital, either because their equity cannot afford them this investment, or because equity would bring a higher return if invested on financial markets.

This would preclude firms from having the theoretical optimal level of capital. Since the adjustment of the labour force comes after the capital investment, we can see that labour will be chosen in order to maximise profit given the level of capital of the firm. This is thus a short-term decision, as firms consider the level of capital to be fixed and must adjust labour accordingly. We note that the optimal labour input L^* derived in the previous section is only optimal if the level of capital is the corresponding one, K^* . To explain it intuitively, consider that the firm has a level of capital $K_1 < K^*$. If the firm were to employ the L^* number of workers, then we would have $L^* > \alpha K_1$ (since $L^* = \alpha K^*$). This means that there would be too many workers costing wages while not producing anything, thus generating an unnecessary loss. Therefore if $K_1 < K^*$ then the level of labour to maximise profit should be $L_1 < L^*$.

Similarly, if the level of capital is $K_2 > K^*$ then the optimal quantity of labour L_2 is not necessarily L^* . Having L^* units of labour will generate a profit $\pi_2 = \pi^* - c(K_2 - K^*)$. There is thus a sunk cost $c(K_2 - K^*)$ which generates a profit less than optimal. Given the right market conditions (i.e. price, wage etc), it could be the case that increasing the amount produced (that is increasing the labour supply) would generate extra revenue which might mitigate the cost of these extra units of capital thus increasing π_2 (though we know

that $\pi_2 < \pi^*$). However since there are decreasing returns to scale, the number of worker L_2 may not be equal to αK_2 because hiring extra workers at a full salary will generate less and less revenue, and this extra revenue may not be sufficient to cover the costs of wages in addition to the already existing cost of capital. In those cases, the firm may be better off incurring the sunk cost than attempting to recover it through extra production.

We thus consider the the problem of maximising profit under a fixed level of capital. The optimisation problem differs from previously. Consider capital to be fixed at $K = \bar{K}$.

The maximisation problem is

$$\max_L \pi_2 = A * \min(L, \alpha \bar{K})^\beta * p - wL - c\bar{K} \quad (\text{E.7})$$

Since there is now only one variable, there is one FOC to verify $\frac{\delta \pi_2}{\delta L} = 0$

We have:

$$\frac{\delta \pi_2}{\delta L} = \begin{cases} A\beta pL^{\beta-1} - w & \text{if } L \leq \alpha \bar{K} \\ -w & \text{if } L > \alpha \bar{K} \end{cases} \quad (\text{E.8})$$

This tells us that the profit function ($\pi_2(L)$) is kinked : it is concave up until $L = \alpha \bar{K}$ and then it is strictly decreasing. It may be the case that the maximum is reached at the kink or on the concave part, this will depend on the level of capital.

The graph below (fig.E.1) illustrates this $\pi_2(L)$ function for different levels of capital. We note that a lower \bar{K} will result in a profit level curve which appears to start "higher" (this is due to capital costs being lower), but the straight decreasing part appears very quickly (blue and red curves). Thus for low levels of capital the maximum profit is reached at the kink. For higher levels (green curves), the maximum point is reached on the concave part of the curve. The purple curves show all the maximum profit points for different levels of capital. We see that the maximum of this curve is reached at the red curve, which corresponds to the profit curve when $K = K^*$, and the maximum point is reached for a level of labour L^* (results obtained for the long run profit). We also see that above a certain level of capital (green curves), the optimal labour force is capped at a point L^{**} . Therefore above this level of capital K^{**} , the firm is better off having less labour units than its capital would technically allow as the sunk cost of the extra capital units may not be recuperated through extra production. The blue (and red) curves correspond to levels

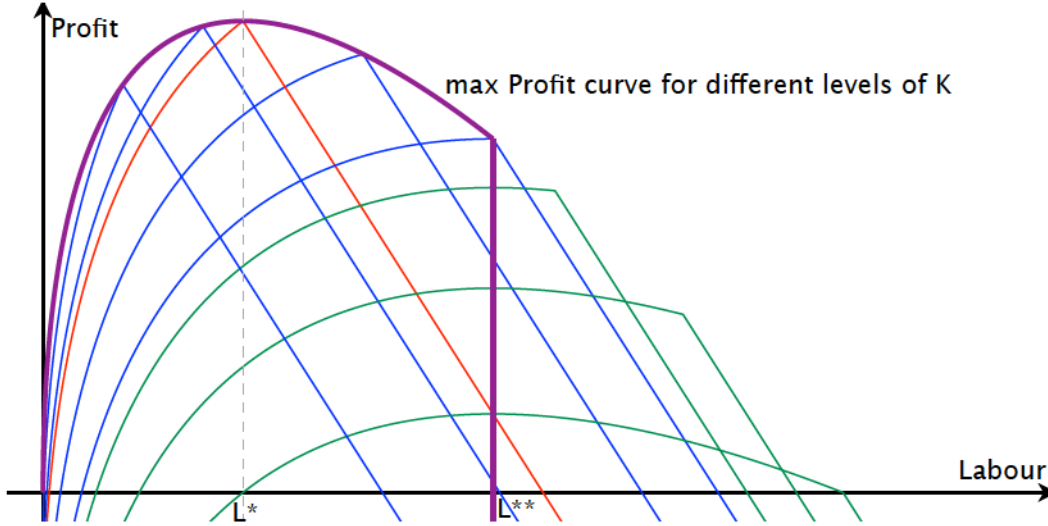


Figure E.1: Profit functions for different levels of fixed capital

of capital for which the firm is better off using the maximum number of labour units that capital would allow (i.e. : $L = \alpha K$).

Now solving for the first order condition, we obtain:

$$\frac{\delta \pi_2}{\delta L} = 0 \iff \begin{cases} A\beta p L^{\beta-1} - w = 0 & \text{if } L \leq \alpha \bar{K} \\ -w = 0 \text{ (impossible)} & \text{if } L > \alpha \bar{K} \end{cases} \quad (\text{E.9})$$

We can solve for the cutoff point

$$L^{**} = \left(\frac{w}{A\beta p} \right)^{\frac{1}{\beta-1}} \quad (\text{E.10})$$

Therefore the optimal quantity of labour $L_{\bar{K}}$ for a quantity of capital \bar{K} :

$$\begin{cases} L_{\bar{K}} = \alpha \bar{K} & \text{if } L^{**} \geq \alpha \bar{K} \\ L_{\bar{K}} = L^{**} & \text{if } L^{**} \leq \alpha \bar{K} \end{cases} \quad (\text{E.11})$$

We can verify that if $\bar{K} = K^*$ then the optimal level of labour will indeed be L^* as determined in the first section.

Say $\bar{K} = K^* = \frac{1}{\alpha} \left(\frac{\alpha w + c}{\alpha A \beta p} \right)^{\frac{1}{\beta-1}}$, then according to (E.11) L_{K^*} will depend on the relationship between L^{**} and αK^* .

$$\begin{aligned} L_{K^*} &= \alpha K^* = L^* & \text{iff } L^{**} \geq \alpha K^* \\ L^{**} &= \left(\frac{w}{A\beta p} \right)^{\frac{1}{\beta-1}} & \alpha K^* = \left(\frac{\alpha w + c}{\alpha A \beta p} \right)^{\frac{1}{\beta-1}} \end{aligned} \quad (\text{E.12})$$

$$\begin{aligned}
L^{**} \geq \alpha K^* &\implies \left(\frac{w}{A\beta p}\right)^{\frac{1}{\beta-1}} \geq \left(\frac{\alpha w+c}{\alpha A\beta p}\right)^{\frac{1}{\beta-1}} \\
\frac{w}{A\beta p} \leq \frac{\alpha w+c}{\alpha A\beta p} &\implies \alpha w \leq \alpha w + c \\
\text{thus } L^{**} \geq \alpha K^* &\text{ iff } c \geq 0
\end{aligned}$$

Since $c > 0$ we know that $L^{**} > \alpha K^*$ therefore $L_{K^*} = \alpha K^* = L^*$.

3 Size of the firm and technology

The long term results obtained in (E.6) tells us some information in regarding the optimal size of the firm and the state of the market. We see that there is a negative relationship between K^* and the wage and capital cost level. This is logical due to the complimentary nature of both inputs. With high maintenance costs, the sunk cost generated by a large firm size is more difficult to outweigh unless the price level in the market justifies it. Due to the decreasing returns to scale, it may be the case that large firms end up sinking faster.

More interestingly for the purpose of our study is the relationship between optimal firm size and the state of the technology. We find that there is a positive relationship between the optimal quantity of inputs and the productivity (A) of the firm. All else equal, the only way a firm can justify an expansion is if they are productive enough, that is there technology is sufficiently strong to carry them through this expansion. In the North-South context, since Northern firms are the ones with the technological advantage, they will be the one with the capital advantage as well, even if both types start with equal levels of capital. Only the Northern firms will be able to start expanding.

Appendix **F**

Simulations

1 Example of a run of the model in Netlogo

In section 3.2.1 we presented an example of the Netlogo interface (fig. F.1) that serves as the tool to configure and run the model. Using the same parameters as specified in this example, we ran the model for the usual 1000 periods and present the results. This section serves as a presentation of how to interpret visually the results obtained and gives an idea of how the model runs with those particular parameters.

The model presented here follows the same basic parameters as the runs in the Monte-Carlo experiment. The situation here is a developing country, where the local industry bears a rather important gap with the technological frontier of the North ($gap = 4$). There are only 3 firms from the north that have entered this local industry. The labour market is fairly flexible, with middle length contracts (100 periods), which means that technically a contract would bind the firm to a worker for 10% of the run, providing no contract is broken (which is a fairly unrealistic observation here, as for this particular run 42 contracts ran their course, 1101 were broken by firms for economic reasons and 2904 were broken by the worker). The inner inequality parameter (education gap *epsilon*) is 20, which represents a deviation of 40% above and below the national average.

After running the model for 1000 periods, we end up with a technological space as presented below in figure F.2. The orange dots represent the technologies learned by the southern firms and the purple dots represent the technologies learned by northern firms.

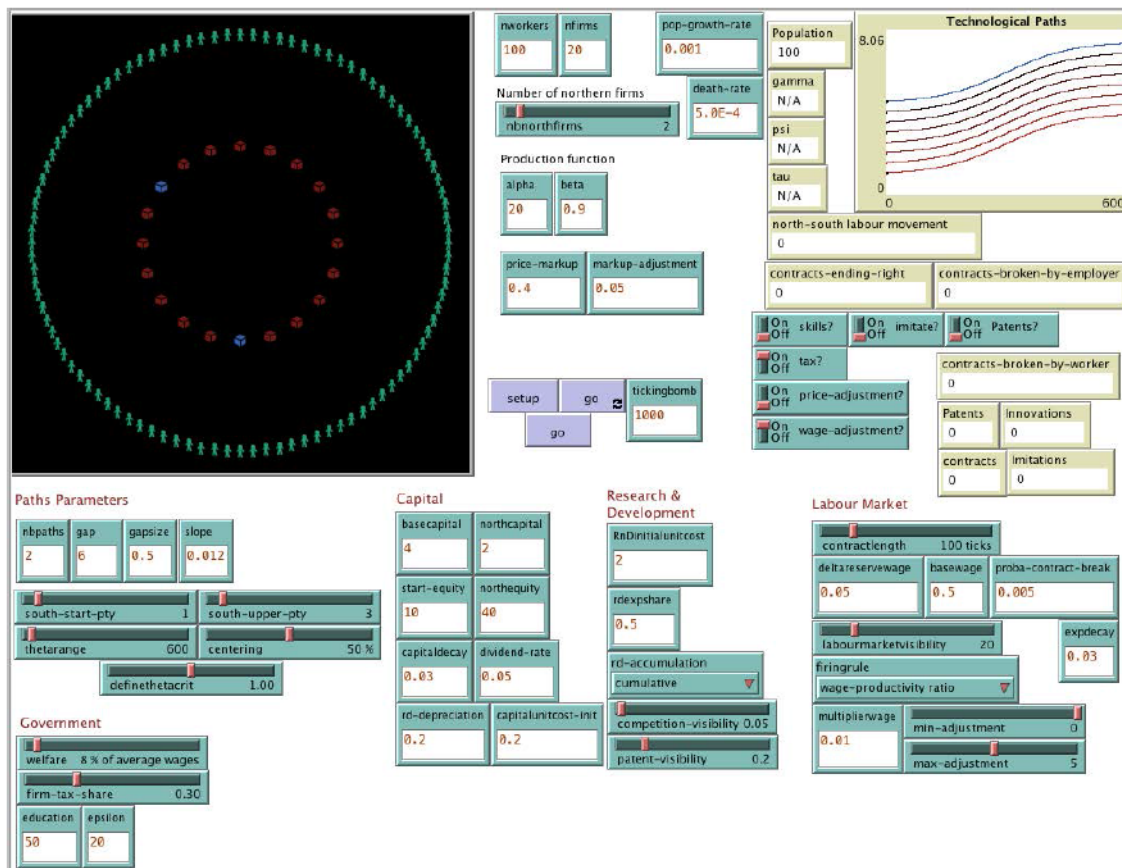


Figure F.1: Example of an initial point of the interface

We can see that at the end of the run, the northern firms are still ahead of the southern firms. Southern firms on the other have managed to make radical innovations that are allowing them to slowly catch up to the northern firms, though they do not seem to have reached this trajectory though these means. Instead it appears that some southern firms have succeeded in imitating the northern firms earlier on, though they remained behind on the trajectory after this imitation was successful.

The plots presented in figure F.3 show what happened during the run. The first plot shows profits in the industry. There are two colour codes mainly used in those plots, either a min-mean-max code, which are respectively represented by red-black-green or north vs south represented by respectively blue and red curves. Profits were on average positive, with at least one firm making losses. Wages overall increased during the time period though they quickly stabilised. Production increased overall : the maximum production for a firm kept increasing, and so did the average. The orange curve on that third plot (starting

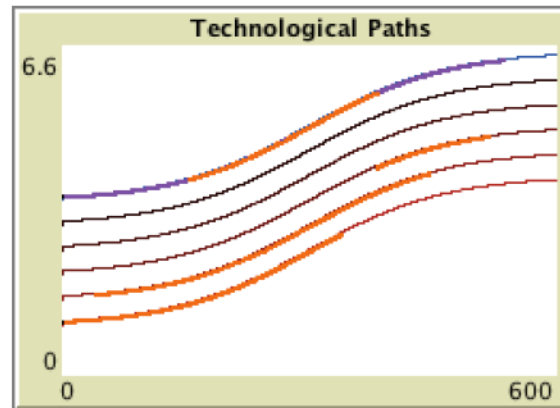


Figure F.2: *Technological space after 1000 periods*

for the left) show the average income from sales, which kept increasing as well. This all resulted in an increase in GDP, thus this model exhibits economic growth.

When comparing North and South profits we observe here that the North started by making important losses from which it later recovered though at the end the South was performing better. Those initial losses comes from the fact that wages paid by the firm to the workers were too high (due to the large productivity), and since the firm had 2 supplementary units of capital, they hired 40 more workers at first ($\alpha = 20$), who were bound by contract, meaning that the firm could not let go of this expensive labour force until they ran out of equity. This seemed to appear quickly as production from the North decreased very fast. They were still above the South for half the period, but then Southern firms took over.

Capital levels first decreased, which suggests that the initial capital given to firms was too high for their capabilities (equity or productivity), though over time average capital increased, which means there was capital investment in the economy. Equity quickly fell to zero while R&D investments kept on increasing at the same time as capital investments, meaning firms usually kept on reinvesting their profits, allowing for technological progress to happen and firms to expand.

Skill levels increased as technology advanced, and since new workers enter with an average level of skill (give or take some amount due to the education level) the median (light blue) and average (black) increased overall.

Gamma (technological distance factor) oscillated, while the Psi factor (the skill requirement factor) seemed to keep close to 1 on average, with only the minimum levels oscillating. It did not seem to reach 0 as everyone started with a sufficiently large skill

level, and firms hired only the most skilled workers. Given that towards the end, the unemployment levels are high, there is always some opportunity to recruit sufficiently skilled workers (i.e. not the long term unemployed workers who saw their skill level fall to 0 over time as they failed to gain employment), like the new workers. It appears that on average though firms always had their effective productivity below their potential (first column, third plot), which means that there was a continuous penalty from workers being either insufficiently skilled or in need of continuous training as technology advanced.

It seems that the supply was following the demand, so this means that the rule for adjusting capital levels (and thus production capacities) while accounting for the market position factor works quite well. The price levels remained quite stable over time.

Finally one flaw that we can observe is that unemployment becomes and stays quite high in the model. Most configuration exhibit this behaviour when it comes to unemployment though some managed to keep it as low as 50%. This created a lasting government debt, which could not be sufficiently managed with the current tax policy. One positive aspect of this problem is that in most model unemployment reaches a level and then stabilises around this levels. Since the unemployment rate stops evolving while population increases, it means that new jobs are being created albeit at an insufficient rate. Some parameters may affect this natural level of unemployment (from my experience it ranged from welfare rate (stimulating demand) to the production function parameters α and β), suggesting that it may be a resolvable issue under given conditions. Furthermore, this issue may also be reinterpreted as the fact realistically, there is more than one industry operating in a country thus meaning there should exist some exterior demand. We chose to have that demand financed by taxes, though if it were a demand coming from workers in other sectors this would not be necessary and thus reduce the increasing tax burden on firms and workers. For example in an emerging economy this other sector could be perceived as the agricultural sector. It is a generally lower paid sector, though as the country develops and wages increase, the wages in other sectors (even lower paid ones like the primary sector) can also be expected to increase, thus resembling the behaviour of our unemployment benefits (lower income based on a small percentage of active workers' wages). As total employment in the current industry does increase (along with capital), we can conclude that despite this high unemployment, the industry manages to effectively grow.

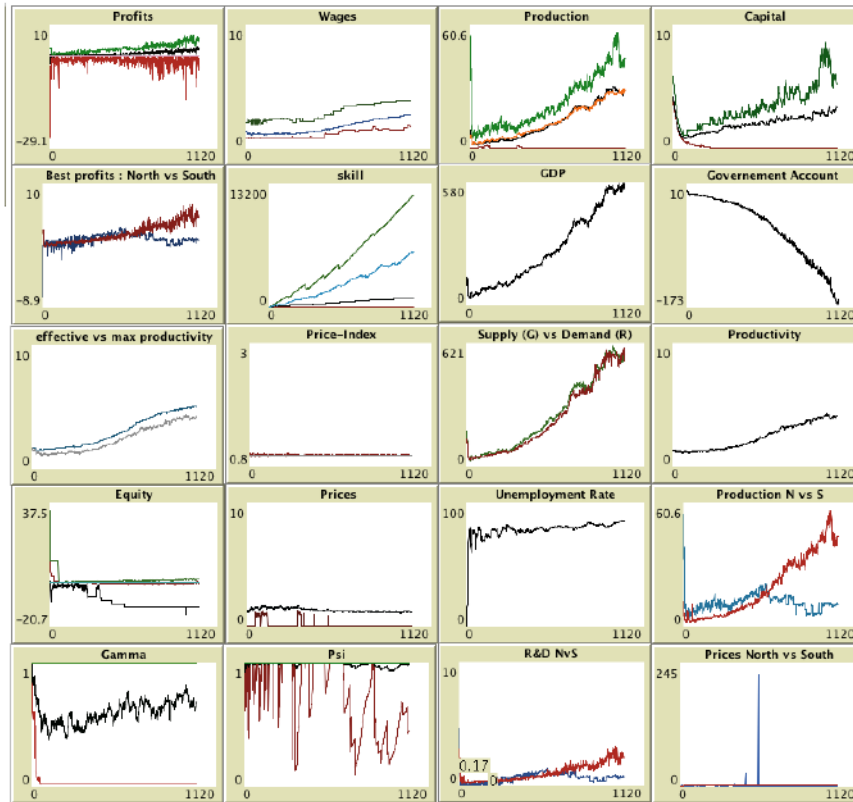


Figure F.3: Example of plots produced after 1000 period run of the model

2 Initial Parameters

2.1 Parameters for both chapters 3 and 4

The model first ran as a Monte-Carlo experiment with in total 2000 runs per configuration. The following starting parameters are fixed for all runs :

Variable	Value	Variable	Value
number of firms	20	theta range	600
initial population	100	delta reserve wage	0.05
welfare	8%	skill decay	0.03
wage markup adjustment	0.05	competition visibility	5%
max wage adjustment	5	initial R&D unit cost	2
min wage adjustment	0	dividend rate	5%
firm tax share	30%	θ^{crit}	1
worker tax share	70%	R&D depreciation	0.2
β	0.9	S_{RD}	75%
labour market visibility	20%	r_{RD}	50%
α	20	w_1	10
slope of technology logistic	0.012	w_2	10
base education	50	educational gap (Ch4 only)	20
initial equity	10	north capital (Ch4 only)	2
population growth rate	0.001	north equity (Ch4 only)	4
retirement rate	0.0005	patent visibility (Ch4 only)	20%
gap size	0.5	patent init cost (Ch4 only)	0.5
south start productivity	1		
base wage	0.5		
price mark up	40%		
probability contract break	0.005		
initial capital unit cost	0.2		
capital depreciatiom	3%		

Table F.1: *Initial Parameters for simulations*

3 The case with no northern firms

We ran 500 simulations of each configuration with no northern firms. This serves as a benchmark to see how the South performs when there are no FDI conducted. The first observation we can make is that the technological gap in this case has no effect on the productivities at the end of the period. This is to be expected given that we set the southern trajectory fixed regardless of the technological gap with the technological frontier, which implies that in all those runs the starting productivity of the South is the same. Furthermore, in the absence of competitors on higher trajectories, there is virtually no impact of the existence of those higher technologies on the South.

The only potential effect could have been that with higher trajectories, as the South innovates the end productivity should have been higher. However, results seems to indicate otherwise. Since the South does not seem to be able to reach higher productivities in the presence of higher technological trajectories, this seems to indicate that the local industry failed at sufficiently innovating. In fact, in our runs, no firm managed to successfully conduct radical innovations. While we could attribute this result to the fact that the probability of those innovations is small in the model, it also highlights the fact that labour turnover is indeed the main channel of technological transfers here. Without any northern firms present, there is virtually no technological transfers from the North facilitating a technological transition.

Keeping the productivity levels even has the advantage of providing a good benchmark configuration. Without the gap, or the competition effects, we can see how other variables affect the performance of the industry.

One such result is the impact of the labour market on the profits (at the end of the period) in the industry as shown in figure F.4. We can see that really short contracts can lead to high profits, though with great variance. This suggests that if a firms are able to adjust their labour force they can optimise profitability. However, other shorts contracts observe a high drop in profit. And from then, as contracts become longer (thus less flexible labour market) average profits increase and stabilise (a lower variance in observed as contracts become particularly long). We tested multiple potential factor and found notably that income from sales increased greatly with contract length, motivated by an increased demand, itself explained by a lower unemployment rate. This lower unemployment rate

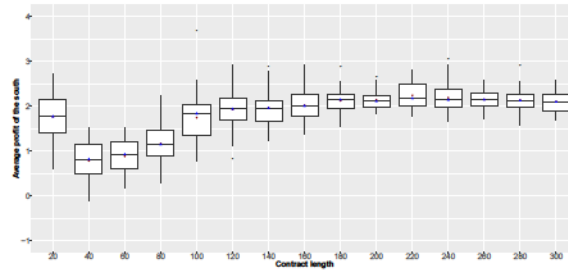


Figure F.4: Mean profits of southern firms when there are no northern firms, per contract length, at the end of the 1000 runs

also causes workers to be more skilled. Therefore we can conclude that longer contracts in this particular setting are highly beneficial to the industries and the workforce.

4 Further plots and tables for the analysis

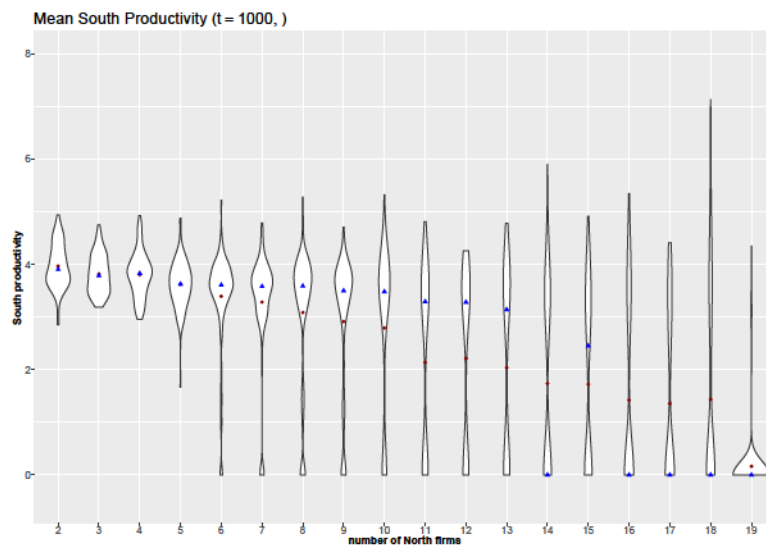


Figure F.5: South mean effective productivity according to the number of northern firms

	<i>Dependent variable:</i>		
	Time of catching-up		
	(1)	(2)	(3)
nbnorthfirms	-2.855 (1.783)	-12.017* (6.719)	-7.855*** (1.943)
nbnorthfirmssq		0.469 (0.333)	
epsilon	0.278 (0.510)	0.298 (0.510)	-0.091 (0.631)
gap	208.742*** (13.260)	207.300*** (13.284)	70.106*** (3.376)
gapsq	-20.294*** (1.542)	-20.148*** (1.545)	
contractlength	0.146 (0.098)	0.161 (0.098)	0.268** (0.104)
basecapital		-4.151 (4.931)	-9.144 (6.166)
south_innovations_adj	0.579*** (0.210)	0.604*** (0.211)	
south_imitations_adj	-5.066*** (0.940)	-5.342*** (0.957)	
northcapital			-6.596 (6.198)
northequity			-0.472 (0.767)
Constant	102.278 (63.008)	146.062** (68.314)	352.889*** (40.599)
R ²	0.597	0.599	0.372
Adjusted R ²	0.594	0.594	0.367
F Statistic	181.686*** (df = 7; 857)	141.740*** (df = 9; 855)	72.454*** (df = 7; 857)

*p<0.1; **p<0.05; ***p<0.01

Table F.2: *Explaining the speed of catching-up*

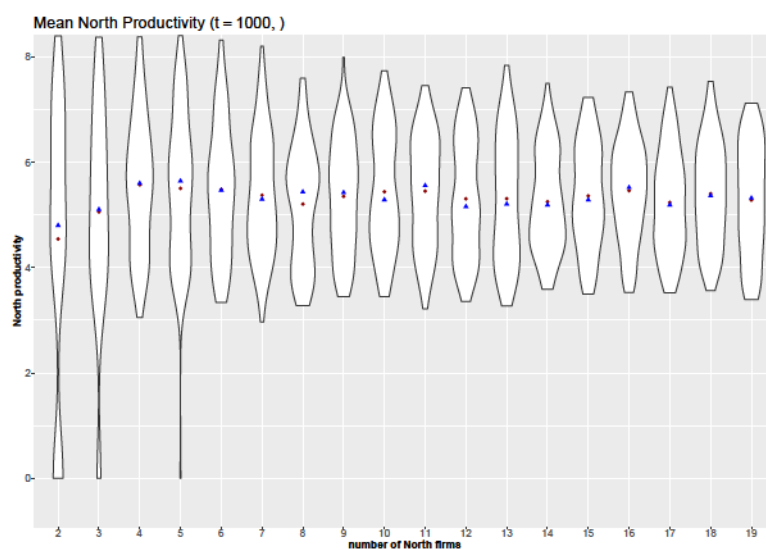


Figure F.6: *North mean effective productivity according to the number of northern firms*

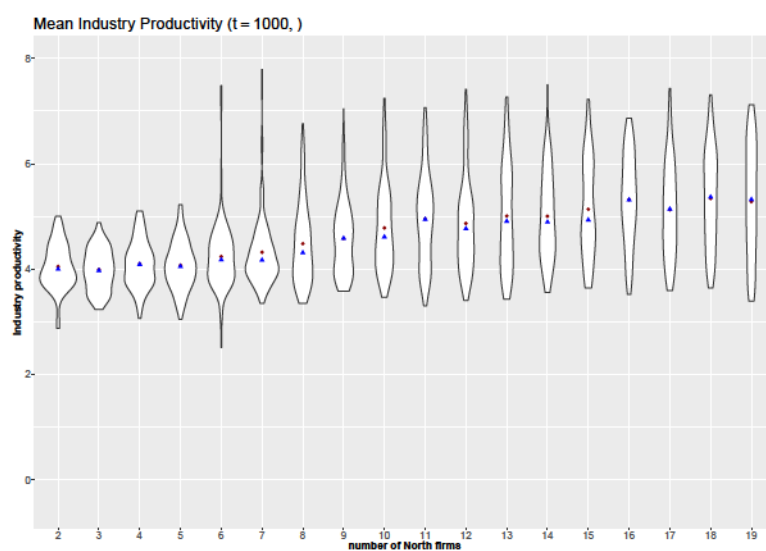


Figure F.7: *Mean effective productivity in the industry according to the number of northern firms*

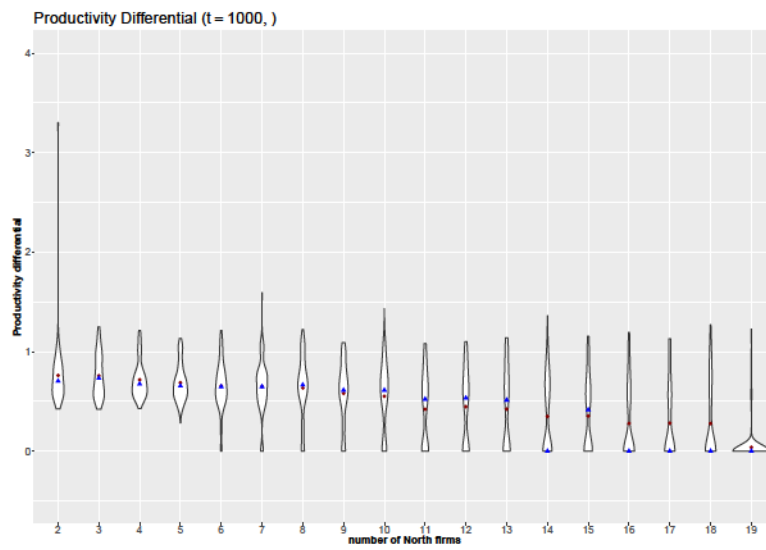


Figure F.8: *South-North productivity differential according to the number of northern firms*

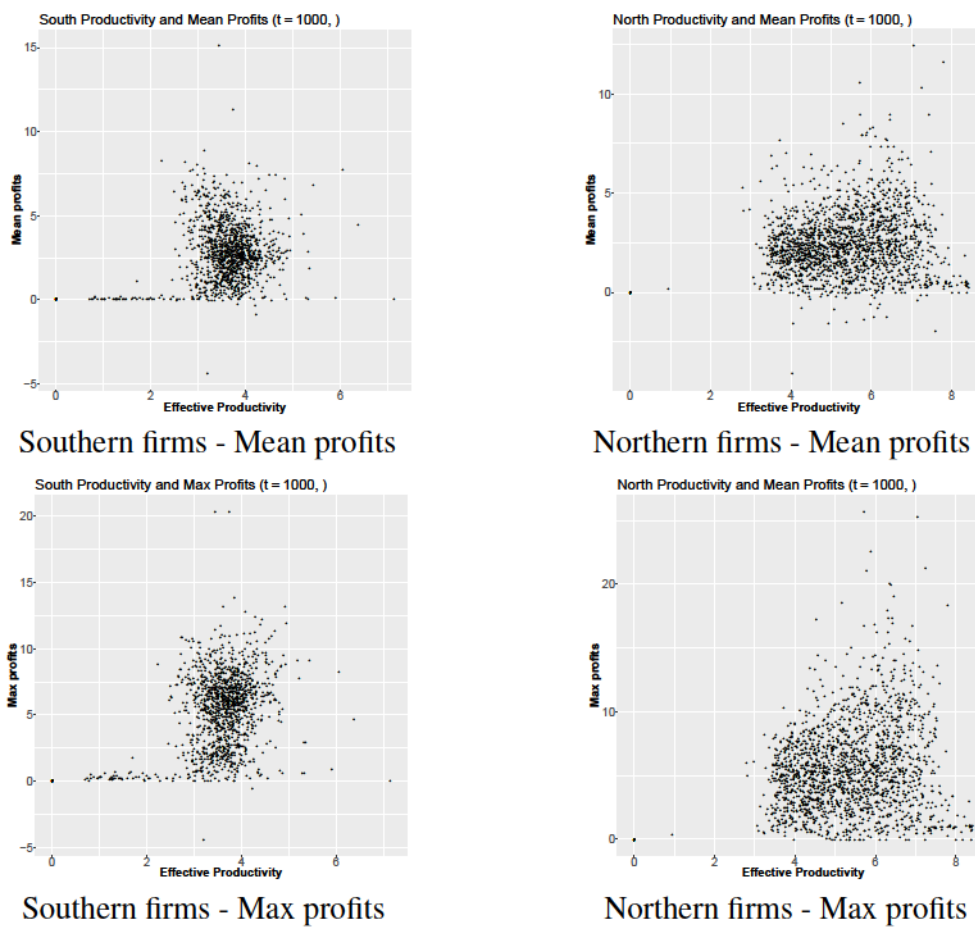
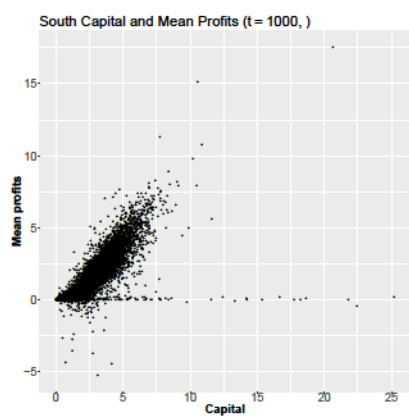
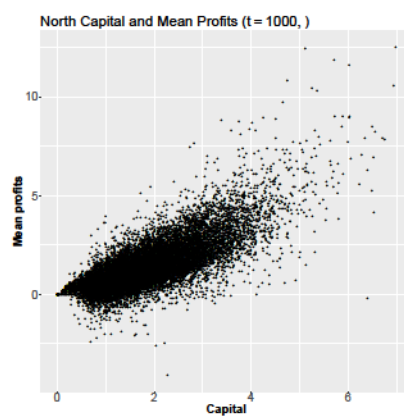


Figure F.9: *Scatter plots showing the relationship between profits and effective productivity at the 1000 period*



Southern firms - Mean Profits

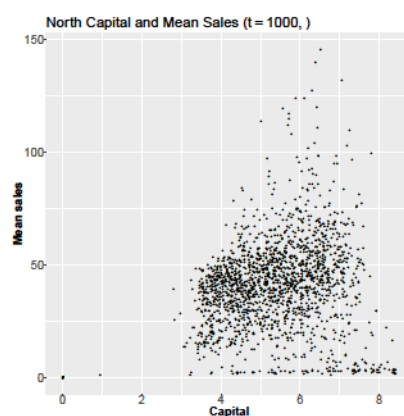


Northern firms - Mean Profits

Figure F.10: *Scatter plots showing the relationship between profits and capital for all periods*



Southern firms - Mean Sales and Effective Productivity



Northern firms - Mean Sales and Effective Productivity

Figure F.11: *Scatter plots showing the relationship between sales and productivity (at period 1000)*

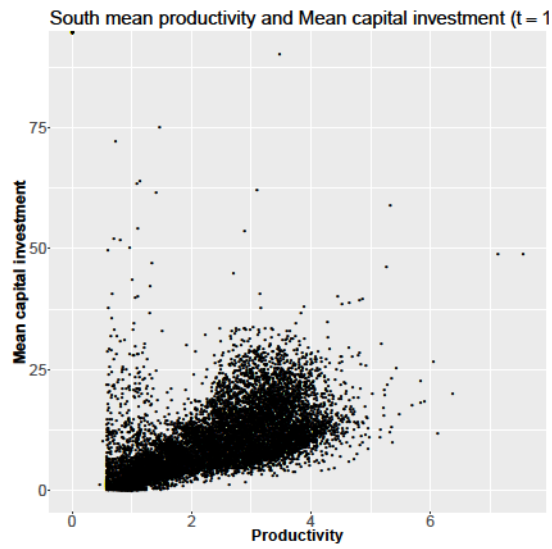


Figure F.12: *Scatter plots showing the relationship between total mean capital investment and productivity (Southern firms, all periods)*

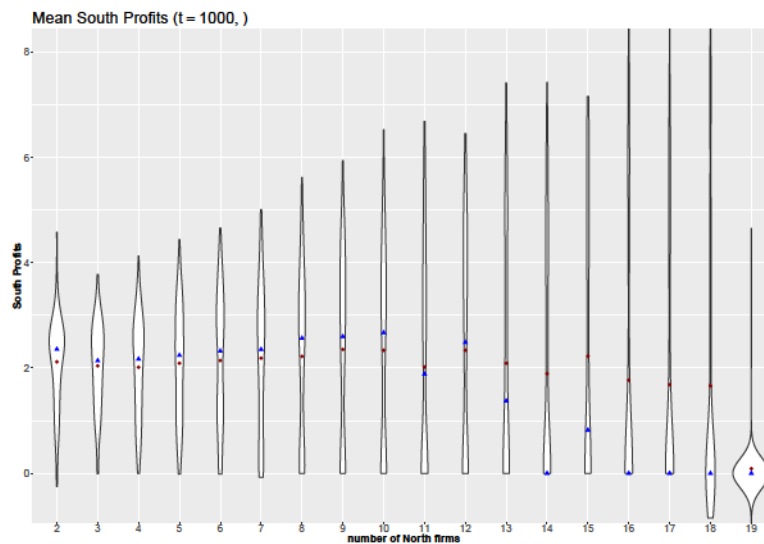


Figure F.13: *Violin plots showing the distribution of profits in the South according to the number of northern firms (at the 1000th period)*

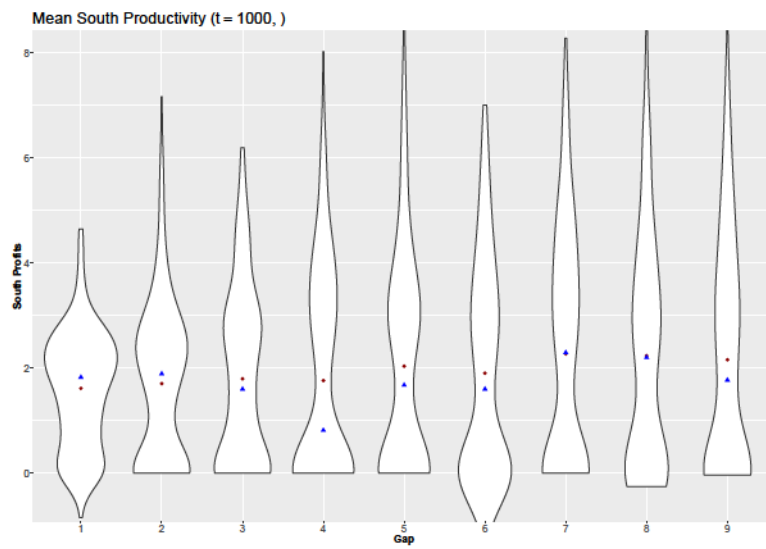


Figure F.14: *Violin plots showing the distribution of profits in the South according to the technological gap (at the 1000th period)*

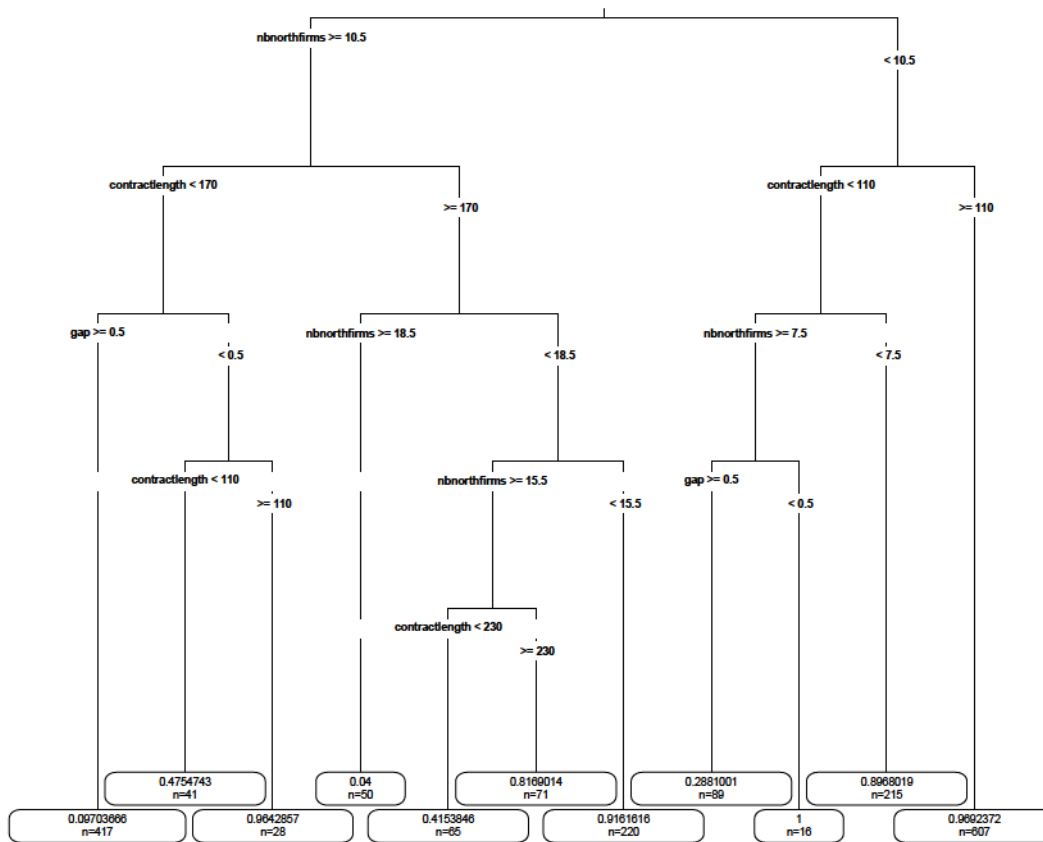


Figure F.15: *Regression tree showing the factors that influence the survival of southern firms (at the 1000th period)*

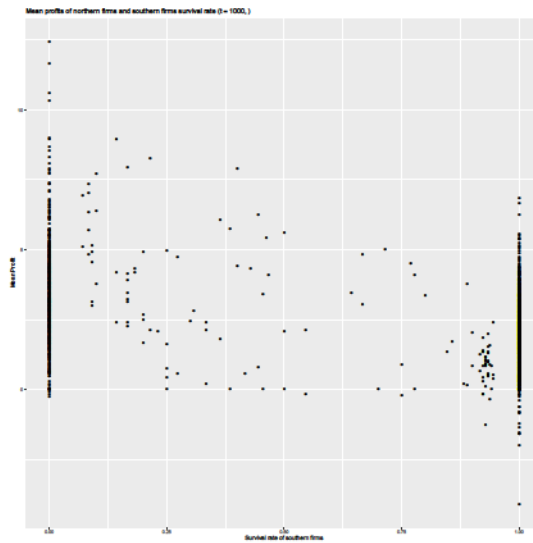


Figure F.16: *Survival rate of southern firms and mean profits reached by northern firms*

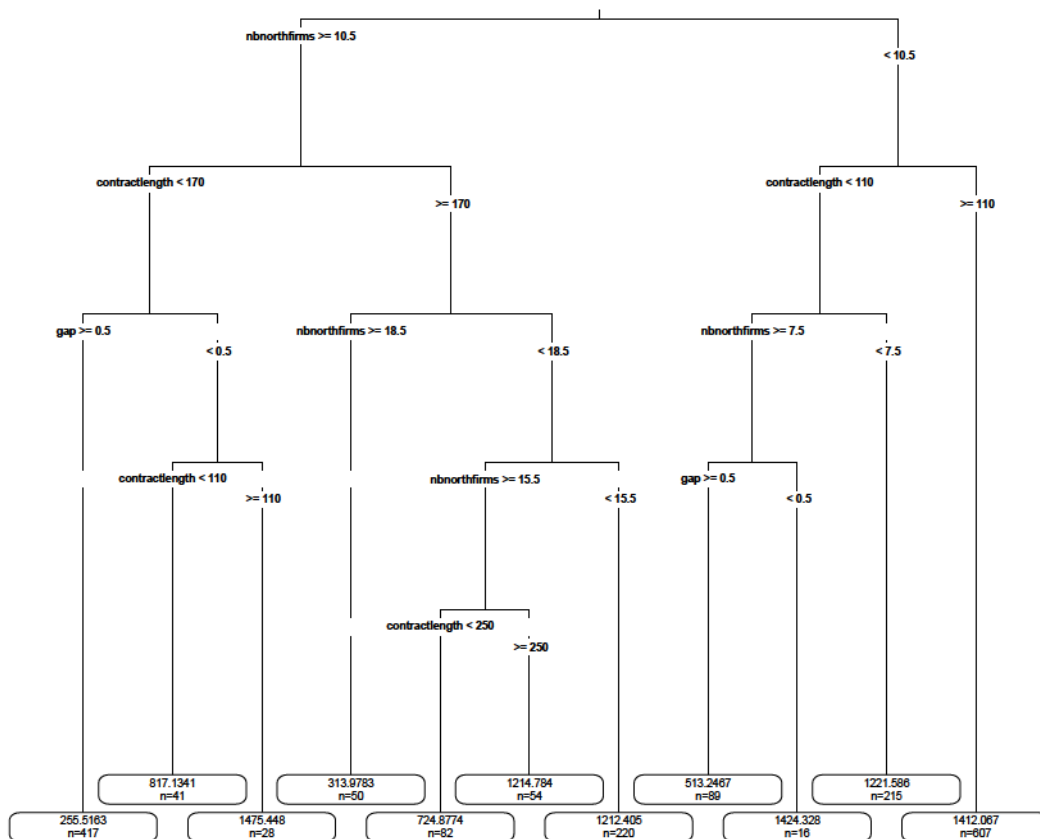


Figure F.17: *Regression tree for the average level of knowledge per southern firm at the 1000th period*

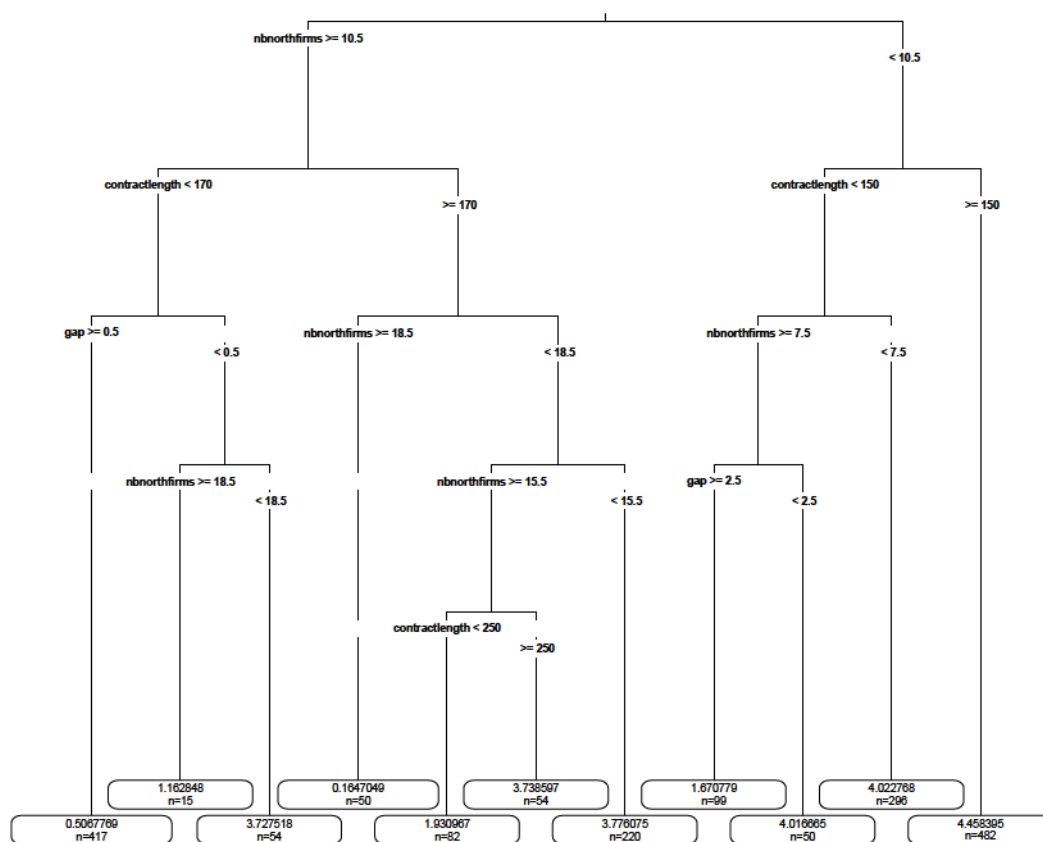


Figure F.18: *Regression tree for the average level of max productivity reached by southern firms at the 1000th period*

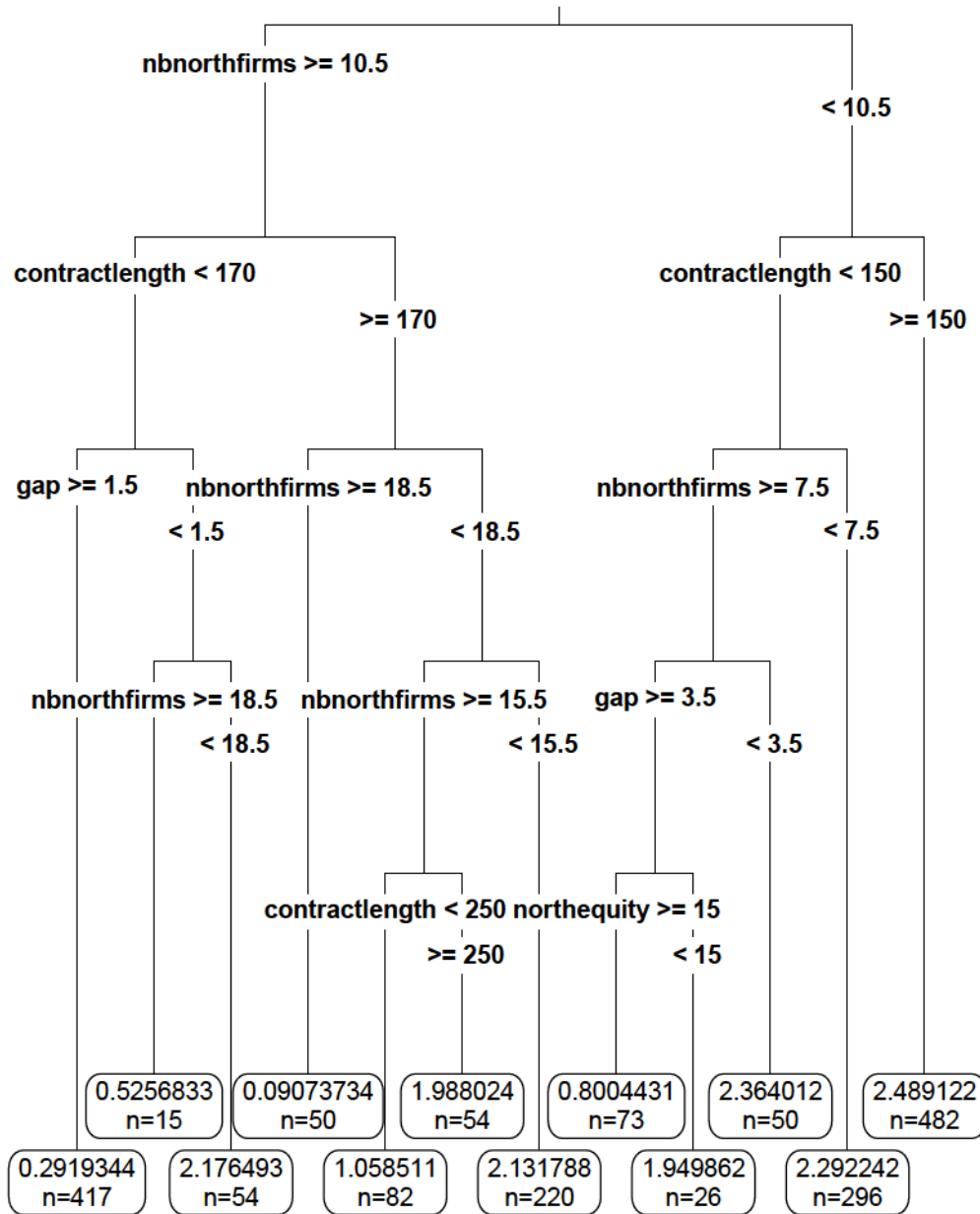


Figure F.19: *Regression trees for South wage levels (at the 1000th period)*

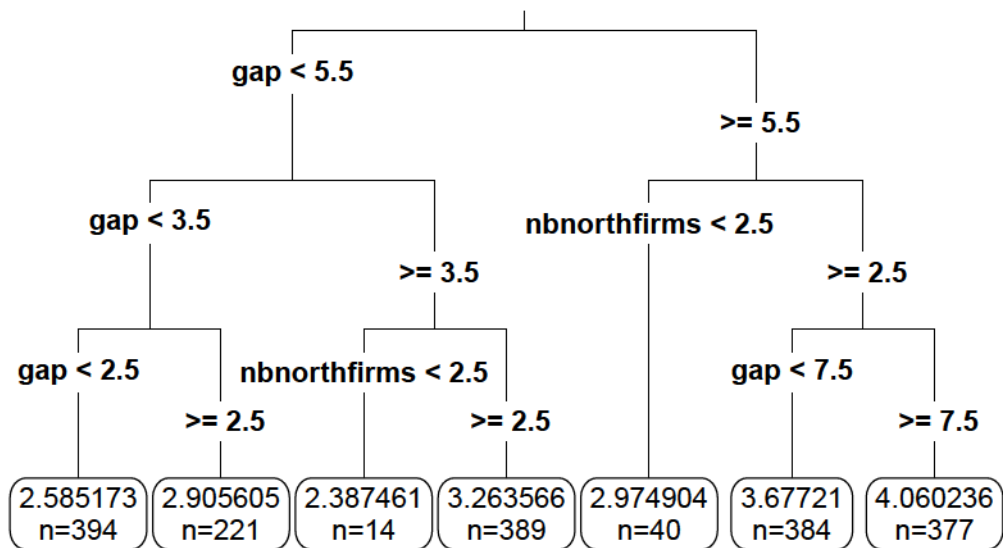


Figure F.20: *Regression trees for North wage levels (at the 1000th period)*

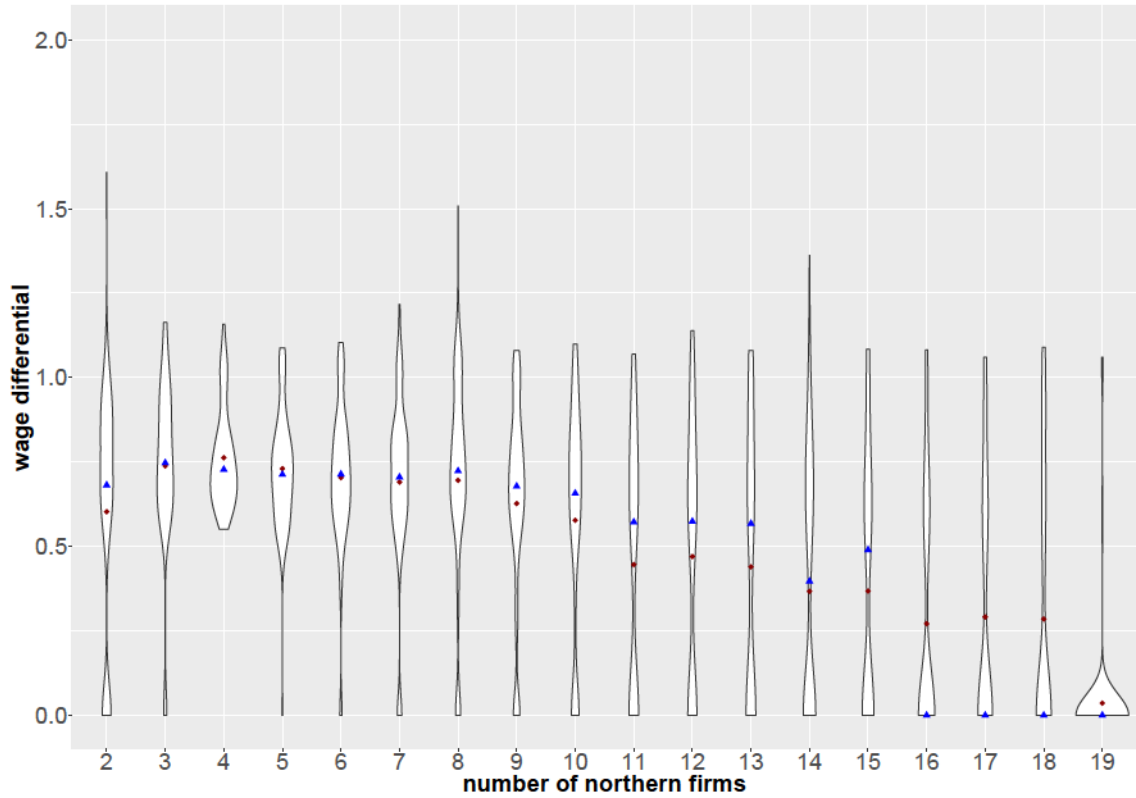


Figure F.21: *Violin plots of the wage differential according to the number of northern firms)*

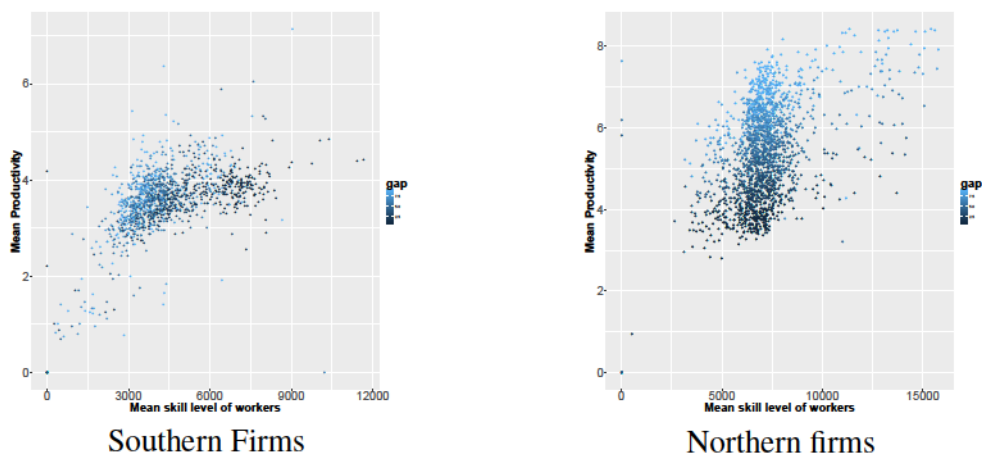


Figure F.22: *Scatter plots showing the relationship between productivity and skill level attained at the 1000th period*

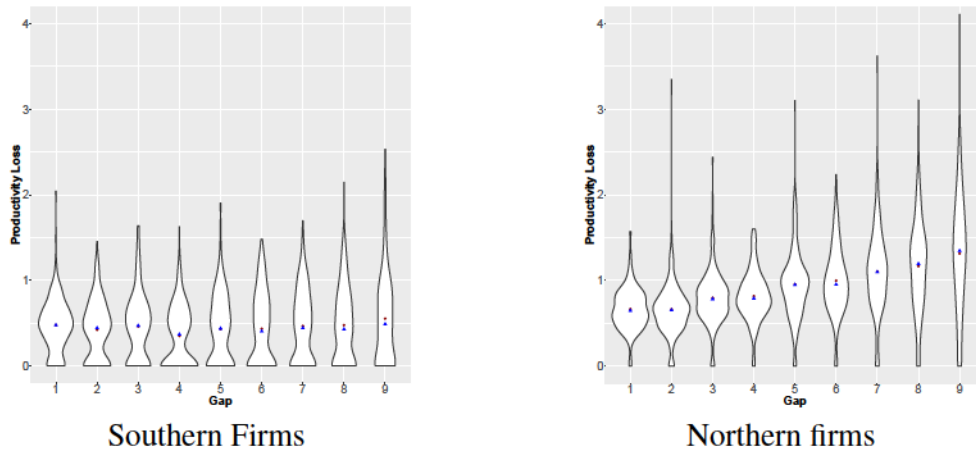


Figure F.23: *Violin Plots : Productivity loss by gap at the 1000th period*

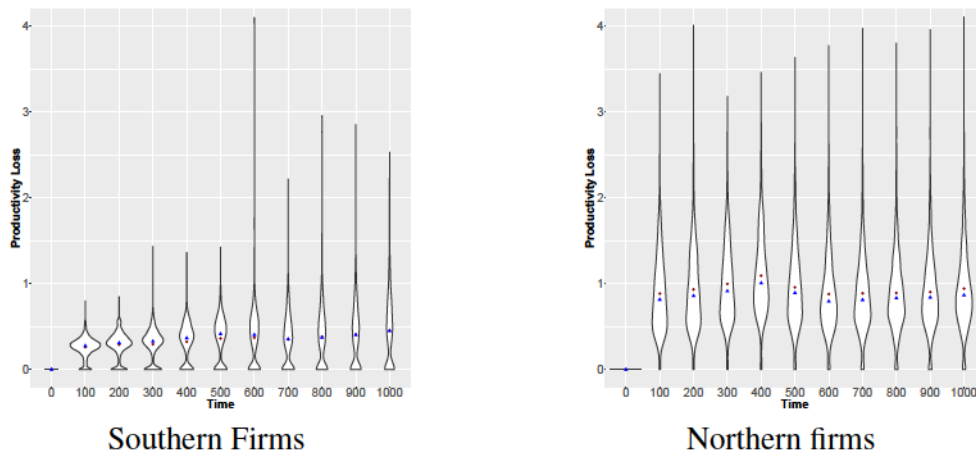


Figure F.24: *Violin Plots : Productivity loss over time at the 1000th period*

Appendix **G**

Introduction - Version Française

Rattrapage économique, Progrès technique et Droits de propriété intellectuelle

Les pays en développement sont confrontés à un environnement technologique de plus en plus complexe, grâce aux pays avancés qui continuent de repousser la frontière technologique. Leur développement est soumis à un contexte bien différent de celui qui a vu naître les Tigres asiatiques, il y a maintenant des décennies. Entre-temps les pays avancés évoluent dans une économie basée sur la connaissance, ce qui les rend dépendants de la création de connaissances au point où les politiques technologiques sont passées au premier plan au niveau national et international. De ce fait, comme ils essaient d'influencer la politique internationale, on se doit de considérer les répercussions sur les pays en développement.

La dépendance sur le progrès technique et le fait que la production de la technologie elle-même devient de plus en plus coûteuse, ont contribué à créer un contexte où l'importance des droits de propriété intellectuelle est amplifiée. Alors que la mondialisation a fait augmenter les interactions économiques entre les pays, le besoin de faire valoir les DPI au-delà de leurs frontières a conduit en 1994 à la ratification d'accords internationaux sur les DPI connus sous le nom de TRIPS. Ces accords, obligatoires pour tous les membres de l'OMC, soit 164 pays, ont forcé un alignement des DPI nationaux sur les recommandations de l'OMC. Alors que pour les pays développés, ces accords n'ont engendré aucun changement puisque les TRIPS suivaient leurs tendances nationales de

renforcement des DPI, pour les pays en développement le changement était plus radical. Ce changement contribue selon Wade (2003) à limiter la capacité "d'auto-détermination" des pays en voie de développement. La question centrale posée dans cette thèse est donc : Est-ce que l'alignement au TRIPS est bénéfique pour les pays en développement?

Cette question n'est pas nouvelle. Le débat autour des TRIPS et de leurs effets sur le développement de ces pays a suscité des études théoriques et empiriques, avec des résultats divergents. La discussion continue donc. Par ailleurs, les pays émergents comme la Chine et l'Inde commencent eux aussi à devenir des acteurs importants du progrès technique à l'échelle internationale, comme en témoigne leurs récentes augmentations de brevets déposés Godinho and Ferreira (2012), ce qui montre aussi que ces pays deviennent aussi des utilisateurs des DPI. Les enjeux ont donc été parfois modifiés pour les pays en développement depuis la signature des TRIPS.

A travers l'Histoire, les politiques de DPI ont vu leurs objectifs et usages changer entre incitations pour la recherche, récompense de l'innovation, encourager le partage technologique et bloquer l'imitation. Et aujourd'hui les firmes les utilisent comme outil stratégique en créant de barrières de brevets contre leurs concurrents. Les DPI peuvent donc impacter le développement économique et technologique de plusieurs manières. Ils encouragent l'innovation tout en limitant l'imitation et en même temps permettent le partage et la diffusion de connaissances. En parallèle les effets sur le marché tels que la création de monopoles et le blocage des concurrents peuvent avoir des effets néfastes sur la performance de l'industrie, ce qui peut être d'autant plus problématique pour le développement des pays avec des secteurs de haute technologie encore naissants. Les TRIPS donnent donc une dimension internationale à la problématique des DPI.

Afin de pouvoir contribuer à cette littérature, la thèse propose de se retourner sur les enjeux principaux des pays en développement, c'est à dire leur rattrapage économique. La thèse est donc organisée d'une manière qui rappelle son titre "Rattrapage économique, progrès technique et droits de propriété intellectuelle". Ainsi pour comprendre les enjeux derrière les DPI, il suffit de voir que ceux-ci sont directement liés au développement technologique. Celui-ci est lui-même lié à la croissance économique comme l'ont souligné très tôt les économistes de la croissance tels que Solow, ou pour la croissance endogène, Romer, Aghion et Howitt. S'il n'est pas nécessaire de rappeler que le développement technologique est crucial pour le rattrapage économique, il peut être intéressant de s'intéresser

aux modalités de ce développement technologique. Plus précisément il s'agit de voir dans quelles mesures l'innovation et l'imitation permettent chacune d'avancer. Il est aussi primordial de comprendre leur rôle afin de pouvoir considérer l'effet des DPI.

Le premier chapitre de la thèse propose donc une analyse sur le rattrapage économique, basée sur le modèle de Verspagen (1991), qui s'intéresse justement à l'imitation et l'innovation et leurs effets sur le potentiel de rattrapage ou de recul des pays en développement. Nous montrons, à travers une étude empirique qui actualise les résultats de l'article de base, que l'innovation est propice au développement, mais que l'imitation est un passage nécessaire pour les pays en développement afin qu'ils puissent construire leurs capacités de développement.

L'importance de l'imitation, qui n'est autre que des transferts de connaissance, nous amène à nous interroger sur les canaux qui véhiculent ces transferts. Une revue rapide de la littérature nous permet de décrire ces canaux et surtout de comprendre les mécanismes sous-jacents. Deux canaux en particulier ressortent, celui du commerce international et les investissements directs à l'étranger (IDE). La complexité et la richesse de ces mécanismes nous guide pour la partie modélisation, qui consiste donc à représenter dans un premier temps les interactions entre pays du Sud et pays du Nord.

Dans le troisième chapitre est développé un modèle à base d'agents (ABM) pour représenter les interactions Nord-Sud. Le choix de ce type de modèle se justifie par le fait que nous observons une diversité de mécanismes complexes et un contexte technologique qui évolue en permanence, ce qui nous amène à prendre une approche évolutionniste pour notre analyse. L'approche évolutionniste, développée par Nelson et Winter (1982) est ancrée sur le concept de rationalité limitée des agents qui fait que ceux-ci sont dépendants de mécanisme d'apprentissage et sélection et d'adaptation pour pouvoir faire des choix. Nelson (2008) note que cette approche est particulièrement adaptée à l'économie du développement compte-tenu de la complexité et de l'évolutivité du contexte qui font que les modèles d'équilibre général ne pourraient pas procurer une analyse complète.

L'utilisation des ABM, et de l'économie computationnelle, est parfaitement adaptée à cette approche, grâce à leur capacité de représenter et tester des systèmes complexes basés sur des processus adaptatifs tels que ceux qui sont inhérents au développement technologique.

Le modèle ABM Nord-Sud développé ici est construit dans sa version de base, mono-sectoriel et représente le canal des IDE, mais propose d'étudier plusieurs aspects de

l'économie, notamment, entre autres, un marché du travail, le développement et transferts de compétences par la main d'oeuvre.

Dans l'esprits des autres modèles ABM macroéconomiques tels que EURACE (Dawid, 2014), le modèle de base peut être étendu afin d'étudier les effets de différentes politiques sur le développement d'un pays. Ainsi le quatrième chapitre propose une extension au modèle qui ajoute un système de brevet, et permettra ainsi de répondre à la question principale.

Si cette thèse a été guidée par une question simple, elle présente tout un travail d'exploration et d'expérimentation de domaines (rattrapage économique, progrès technique et DPI) qui ont été étudiés, mais demandent une nouvelle approche.

Bibliography

Bibliography

- Abramovitz, M.: 1986, Catching up, forging ahead, and falling behind, Journal of Economic history **46**(2), 385–406.
- Acemoglu, D. and Zilibotti, F.: 2001, Productivity differences, The Quarterly Journal of Economics **116**(2), 563–606.
- Aghion, P., Caroli, E. and Garcia-Penalosa, C.: 1999, Inequality and economic growth: the perspective of the new growth theories, Journal of Economic literature **37**(4), 1615–1660.
- Aghion, P. and Howitt, P.: 1990, A model of growth through creative destruction, Technical report, National Bureau of Economic Research.
- Aitken, B. J. and Harrison, A. E.: 1999, Do domestic firms benefit from direct foreign investment? evidence from venezuela, American economic review pp. 605–618.
- Alvarez, R. and Lopez, R. A.: 2005, Exporting and performance: evidence from chilean plants, Canadian Journal of Economics/Revue canadienne d'économique **38**(4), 1384–1400.
- Amiti, M. and Konings, J.: 2007, Trade liberalization, intermediate inputs, and productivity: Evidence from indonesia, The American Economic Review pp. 1611–1638.
- Arrow, K.: 1962, Economic welfare and the allocation of resources for invention, The rate and direction of inventive activity: Economic and social factors, Princeton University Press, pp. 609–626.
- Ballot, G., Kant, J.-D. and Goudet, O.: 2013, Modeling both sides of the french labor market with adaptive agents under bounded rationality, The 25th Annual Conference of the EAEPE (European Association for Evolutionary Political Economy).

- Barro, R. J., Sala-i Martin, X., Blanchard, O. J. and Hall, R. E.: 1991, Convergence across states and regions, Brookings papers on economic activity pp. 107–182.
- Baumol, W.: 1986, Productivity growth, convergence, and welfare: what the long-run data show, The American Economic Review pp. 1072–1085.
- Bergmann, B. R.: 1974, A microsimulation of the macroeconomy with explicitly represented money flows, Annals of Economic and Social Measurement, Volume 3, number 3, NBER, pp. 475–489.
- Blalock, G. and Gertler, P.: 2003, Technology from foreign direct investment and welfare gains through the supply chain, Technical report, mimeo, Cornell University.
- Blalock, G. and Gertler, P. J.: 2004, Learning from exporting revisited in a less developed setting, Journal of Development Economics **75**(2), 397–416.
- Blalock, G. and Veloso, F. M.: 2007, Imports, productivity growth, and supply chain learning, World Development **35**(7), 1134–1151.
- Blomström, M. and Persson, H.: 1983, Foreign investment and spillover efficiency in an underdeveloped economy: evidence from the mexican manufacturing industry, World development **11**(6), 493–501.
- Branstetter, L., Fisman, R., Foley, C. F. and Saggi, K.: 2011, Does intellectual property rights reform spur industrial development?, Journal of International Economics **83**(1), 27–36.
- Chen, Y. and Puttitanun, T.: 2005, Intellectual property rights and innovation in developing countries, Journal of development economics **78**(2), 474–493.
- Cimoli, M., Dosi, G., Mazzoleni, R. and Sampat, B.: 2011, Innovation, technical change and patents in the development process: A long term view.
- Cimoli, M., Dosi, G., Nelson, R. R., Stiglitz, J. E. et al.: 2009, Institutions and policies in developing economies, Chapters .
- Clerides, S. K., Lach, S. and Tybout, J. R.: 1998, Is learning by exporting important? micro-dynamic evidence from colombia, mexico, and morocco, Quarterly journal of Economics pp. 903–947.

- Coe, D. T. and Helpman, E.: 1995, International r&d spillovers, European economic review **39**(5), 859–887.
- Cohen, W. M. and Levinthal, D. A.: 1990, Absorptive capacity: A new perspective on learning and innovation, Administrative science quarterly pp. 128–152.
- Cohen, W. M., Nelson, R. R. and Walsh, J. P.: 2000, Protecting their intellectual assets: Appropriability conditions and why us manufacturing firms patent (or not), Technical report, National Bureau of Economic Research.
- Connolly, M.: 2003, The dual nature of trade: measuring its impact on imitation and growth, Journal of Development Economics **72**(1), 31–55.
- Corless, R. M., Gonnet, G. H., Hare, D. E., Jeffrey, D. J. and Knuth, D. E.: 1996, On the lambertw function, Advances in Computational mathematics **5**(1), 329–359.
- Crespo, N. and Fontoura, M. P.: 2007, Determinant factors of fdi spillovers—what do we really know?, World development **35**(3), 410–425.
- Currie, D., Levine, P., Pearlman, J. and Chui, M.: 1999, Phases of imitation and innovation in a north-south endogenous growth model, Oxford Economic Papers **51**(1), 60–88.
- Damijan, J. P., Knell, M., Majcen, B. and Rojec, M.: 2003a, The role of fdi, r&d accumulation and trade in transferring technology to transition countries: evidence from firm panel data for eight transition countries, Economic systems **27**(2), 189–204.
- Damijan, J. P., Knell, M. S., Majcen, B. and Rojec, M.: 2003b, Technology transfer through fdi in top-10 transition countries: How important are direct effects, horizontal and vertical spillovers?
- Dawid, H., Gemkow, S., Harting, P. and Neugart, M.: 2013, Labor market integration policies and the convergence of regions: the role of skills and technology diffusion, The Two Sides of Innovation, Springer, pp. 167–186.
- Dawid, H., Gemkow, S., Harting, P., van der Hoog, S. and Neugart, M.: 2014, Agent-based macroeconomic modeling and policy analysis: the eurace@ unibi model.
- De Long, J. B. and Summers, L. H.: 1993, How strongly do developing economies benefit from equipment investment?, Journal of Monetary Economics **32**(3), 395–415.

- Dinopoulos, E. and Segerstrom, P.: 2010, Intellectual property rights, multinational firms and economic growth, Journal of Development Economics **92**(1), 13–27.
- Diwan, I. and Rodrik, D.: 1991, Patents, appropriate technology, and north-south trade, Journal of International Economics **30**(1), 27–47.
- Dosi, G.: 1982, Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change, Research policy **11**(3), 147–162.
- Dosi, G., Fagiolo, G. and Roventini, A.: 2010, Schumpeter meeting keynes: A policy-friendly model of endogenous growth and business cycles, Journal of Economic Dynamics and Control **34**(9), 1748–1767.
- Dosi, G. and Nelson, R. R.: 1994, An introduction to evolutionary theories in economics, Journal of evolutionary economics **4**(3), 153–172.
- Drahos, P.: 2002, Developing countries and international intellectual property standard-setting, The Journal of World Intellectual Property **5**(5), 765–789.
- Eaton, J. and Kortum, S.: 2001, Trade in capital goods, European Economic Review **45**(7), 1195–1235.
- Eliasson, G.: 1977, Competition and market processes in a simulation model of the swedish economy, The American Economic Review **67**(1), 277–281.
- Fagerberg, J. and Srholec, M.: 2008, National innovation systems, capabilities and economic development, Research policy **37**(9), 1417–1435.
- Fagerberg, J., Srholec, M. et al.: 2015, Capabilities, competitiveness, nations, Technical report, Lund University, CIRCLE-Center for Innovation, Research and Competences in the Learning Economy.
- Falvey, R., Foster, N. and Greenaway, D.: 2006, Intellectual property rights and economic growth, Review of Development Economics **10**(4), 700–719.
- Fosfuri, A., Motta, M. and Rønde, T.: 2001, Foreign direct investment and spillovers through workers' mobility, Journal of international economics **53**(1), 205–222.

- Gallini, N. T.: 1992, Patent policy and costly imitation, The RAND Journal of Economics pp. 52–63.
- Gerschenkron, A.: 1962, Economic backwardness in historical perspective: a book of essays, Technical report, Belknap Press of Harvard University Press Cambridge, MA.
- Gilbert, R. and Shapiro, C.: 1990, Optimal patent length and breadth, The RAND Journal of Economics pp. 106–112.
- Glass, A. J. and Saggi, K.: 1999, Foreign direct investment and the nature of r&d, Canadian journal of Economics pp. 92–117.
- Glass, A. J. and Saggi, K.: 2002, Intellectual property rights and foreign direct investment, Journal of International economics **56**(2), 387–410.
- Globerman, S.: 1979, Foreign direct investment and 'spillover' efficiency benefits in canadian manufacturing industries, Canadian journal of economics pp. 42–56.
- Godinho, M. M. and Ferreira, V.: 2012, Analyzing the evidence of an ipr take-off in china and india, Research Policy **41**(3), 499–511.
- Görg, H. and Greenaway, D.: 2004, Much ado about nothing? do domestic firms really benefit from foreign direct investment?, The World Bank Research Observer **19**(2), 171–197.
- Görg, H. and Strobl, E.: 2005, Spillovers from foreign firms through worker mobility: An empirical investigation*, The Scandinavian journal of economics **107**(4), 693–709.
- Grossman, G. M. and Helpman, E.: 1991, Trade, knowledge spillovers, and growth, European Economic Review **35**(2), 517–526.
- Haddad, M. and Harrison, A.: 1993, Are there positive spillovers from direct foreign investment?: Evidence from panel data for morocco, Journal of development Economics **42**(1), 51–74.
- Hale, G., Long, C. X. et al.: 2006, What determines technological spillovers of foreign direct investment: evidence from China, Economic Growth Center, Yale University New Haven, CT.

- Hall, B. H. and Ziedonis, R. H.: 2001, The patent paradox revisited: an empirical study of patenting in the us semiconductor industry, 1979-1995, RAND Journal of Economics pp. 101–128.
- Helpman, E.: 1993, Innovation, imitation, and intellectual property rights, Econometrica **61**(6), 1247–1280.
URL: <http://www.jstor.org/stable/2951642>
- Horner, R.: 2014, The impact of patents on innovation, technology transfer and health: a pre-and post-trips analysis of india’s pharmaceutical industry, New Political Economy **19**(3), 384–406.
- Jabbour, L. and Mucchielli, J. L.: 2007, Technology transfer through vertical linkages: The case of the spanish manufacturing industry, Journal of Applied Economics **10**(1), 115–136.
- Javorcik, B. S.: 2004, Does foreign direct investment increase the productivity of domestic firms? in search of spillovers through backward linkages, American economic review pp. 605–627.
- Javorcik, B. S., Özden, Ç., Spatareanu, M. and Neagu, C.: 2011, Migrant networks and foreign direct investment, Journal of Development Economics **94**(2), 231–241.
- Javorcik, B. S. and Spatareanu, M.: 2008, To share or not to share: Does local participation matter for spillovers from foreign direct investment?, Journal of development Economics **85**(1), 194–217.
- Katrak, H.: 1990, Imports of technology and the technological effort of indian enterprises, World Development **18**(3), 371–381.
- Kaufmann, D., Kraay, A., Zoido-Lobatón, P. et al.: 1999, Aggregating governance indicators, Vol. 2195, World Bank, Development Research Group, Macroeconomics and Growth, and World Bank Institute, Governance, Regulation, and Finance.
- Keller, W.: 2001, International technology diffusion, Technical report, National bureau of economic research.

- Kim, L.: 1980, Stages of development of industrial technology in a developing country: a model, Research policy **9**(3), 254–277.
- Kim, Y. K., Lee, K., Park, W. G. and Choo, K.: 2012, Appropriate intellectual property protection and economic growth in countries at different levels of development, Research policy **41**(2), 358–375.
- Klemperer, P.: 1990, How broad should the scope of patent protection be?, The RAND Journal of Economics pp. 113–130.
- Kokko, A.: 1992, Foreign direct investment, host country characteristics and spillovers.
- Krugman, P.: 1979, A model of innovation, technology transfer, and the world distribution of income, the Journal of political economy pp. 253–266.
- La Croix, S. J. and Kawaura, A.: 1996, Product patent reform and its impact on korea's pharmaceutical industry, International Economic Journal **10**(1), 109–124.
- Lai, E. L.-C.: 1998, International intellectual property rights protection and the rate of product innovation, Journal of Development economics **55**(1), 133–153.
- Lall, S.: 1992, Technological capabilities and industrialization, World development **20**(2), 165–186.
- Lall, S.: 2000, Technological change and industrialization in the asian newly industrializing economies: achievements and challenges, Technology, learning and innovation: Experiences of newly industrializing economies pp. 13–68.
- Lall, S.: 2003, Indicators of the relative importance of iprs in developing countries, Research Policy **32**(9), 1657–1680.
- Lanjouw, J. O.: 1998, The introduction of pharmaceutical product patents in india: "heartless exploitation of the poor and suffering"?, Technical report, National Bureau of Economic Research.
- Lee, J.-Y. and Mansfield, E.: 1996, Intellectual property protection and us foreign direct investment, The review of Economics and Statistics pp. 181–186.

- Lesser, W.: 2001, The effects of trips-mandated intellectual property rights on economic activities in developing countries, World Intellectual Property (WIPO) Studies **1**, 1–24.
- Lin, P. and Saggi, K.: 2004, Ownership structure and technological upgrading in international joint ventures, Review of Development Economics **8**(2), 279–294.
- Liu, Z.: 2008, Foreign direct investment and technology spillovers: Theory and evidence, Journal of Development Economics **85**(1), 176–193.
- Lundvall, B.-Å.: 2007, National innovation systems—analytical concept and development tool, Industry and innovation **14**(1), 95–119.
- Machlup, F.: 1958, An economic review of the patent system, number 15, US Government Printing Office.
- Markusen, J. R. and Venables, A. J.: 1999, Foreign direct investment as a catalyst for industrial development, European economic review **43**(2), 335–356.
- Merges, R. P. and Nelson, R. R.: 1990, On the complex economics of patent scope, Columbia Law Review **90**(4), 839–916.
- Merlevede, B., Schoors, K. and Spatareanu, M.: 2014, Fdi spillovers and time since foreign entry, World Development **56**, 108–126.
- Moran, T.: 2001, Parental supervision: the new paradigm for foreign direct investment and development” institute for international economics, washington dc.
- Nelson, R. R.: 2008, Economic development from the perspective of evolutionary economic theory, Oxford development studies **36**(1), 9–21.
- Nelson Richard, R. and Winter Sidney, G.: 1982, An evolutionary theory of economic change, Harvard Business School Press, Cambridge .
- Parello, C. P.: 2008, A north–south model of intellectual property rights protection and skill accumulation, Journal of Development Economics **85**(1), 253–281.
- Park, W. G., LIPPOLDT, D. et al.: 2014, Channels of technology transfer and intellectual property rights in developing countries, Intellectual Property Rights for Economic Development, Edward Elgar Publishers pp. 33–89.

- Quah, D. T.: 1997, Empirics for growth and distribution: stratification, polarization, and convergence clubs, Journal of economic growth **2**(1), 27–59.
- Radosevic, S.: 1999, International technology transfer and catch-up in economic development.
- Rodriguez-Clare, A.: 1996, Multinationals, linkages, and economic development, The American Economic Review pp. 852–873.
- Romer, P. M.: 1990, Endogenous technological change, Journal of political Economy **98**(5, Part 2), S71–S102.
- Saggi, K.: 2002, Trade, foreign direct investment, and international technology transfer: A survey, The World Bank Research Observer **17**(2), 191–235.
- Sala-i Martin, X. and Barro, R. J.: 1995, Technological diffusion, convergence and growth, Technical report.
- Schiff, M. and Wang, Y.: 2006, On the quantity and quality of knowledge: The impact of openness and foreign r&d on north-north and north-south technology spillovers, Global Integration and Technology Transfer. New York: Palgrave Macmillan and World Bank .
- Scotchmer, S.: 2004, Innovation and incentives, MIT press.
- Şener, F.: 2006, Intellectual property rights and rent protection in a north-south product-cycle model, Manuscript, Union College, Schenectady .
- Silverberg, G. and Verspagen, B.: 1994, Collective learning, innovation and growth in a boundedly rational, evolutionary world, Journal of Evolutionary Economics **4**(3), 207–226.
- Smith, P. J.: 1999, Are weak patent rights a barrier to us exports?, Journal of International Economics **48**(1), 151–177.
- Solow, R. M.: 1956, A contribution to the theory of economic growth, The quarterly journal of economics **70**(1), 65–94.

- Srinivas, S. and Sutz, J.: 2008, Developing countries and innovation: Searching for a new analytical approach, Technology in Society **30**(2), 129–140.
- Sykes, A. O.: 2002, Trips, pharmaceuticals, developing countries, and the doha'solution', U Chicago Law and Economics Olin Working Paper No. 140.
- Taymaz, E. and Lenger, A.: 2004, Multinational corporations as a vehicle for productivity spillovers in turkey, Technical report, DRUID, Copenhagen Business School, Department of Industrial Economics and Strategy/Aalborg University, Department of Business Studies.
- Teece, D. J.: 2010, Technological innovation and the theory of the firm: the role of enterprise-level knowledge, complementarities, and (dynamic) capabilities, Handbook of the Economics of Innovation **1**, 679–730.
- Teece, D. J. et al.: 1977, Technology transfer by multinational firms: The resource cost of transferring technological know-how, Economic journal **87**(346), 242–261.
- Vallée, T. and Yildizoğlu, M.: 2006, Social and technological efficiency of patent systems, Journal of Evolutionary Economics **16**(1-2), 189–206.
- Van Biesebroeck, J.: 2005, Exporting raises productivity in sub-saharan african manufacturing firms, Journal of International economics **67**(2), 373–391.
- Van Dijk, T.: 1994, The economic theory of patents: a survey, Merit.
- Veblen, T.: 1898, Why is economics not an evolutionary science?, The quarterly journal of economics **12**(4), 373–397.
- Verspagen, B.: 1991, A new empirical approach to catching up or falling behind, Structural change and economic dynamics **2**(2), 359–380.
- Vishwasrao, S.: 1994, Intellectual property rights and the mode of technology transfer, Journal of Development Economics **44**(2), 381–402.
- Wade, R. H.: 2003, What strategies are viable for developing countries today? the world trade organization and the shrinking of 'development space', Review of international political economy **10**(4), 621–644.

- Wang, J.-Y. and Blomström, M.: 1992, Foreign investment and technology transfer: A simple model, European economic review **36**(1), 137–155.
- Xu, B.: 2000, Multinational enterprises, technology diffusion, and host country productivity growth, Journal of Development Economics **62**(2), 477–493.
- Xu, B. and Chiang, E. P.: 2005, Trade, patents and international technology diffusion, The Journal of International Trade & Economic Development **14**(1), 115–135.
- Xu, B. and Wang, J.: 1999, Capital goods trade and r&d spillovers in the oecd, Canadian Journal of Economics pp. 1258–1274.
- Yang, G. and Maskus, K. E.: 2001, Intellectual property rights, licensing, and innovation in an endogenous product-cycle model, Journal of International Economics **53**(1), 169–187.

0.0.0.1