ABSTRACT

COLLINS, TRACY MICHELLE. Technology Diffusion, Learning from Imitation, and Growth. (Under the direction of John Seater).

The empirical evidence clearly shows that some former developing countries have learned how to innovate, but no theoretical model has adequately been able to explain this phenomenon until now. When I incorporate a learning to innovate effect into a traditional product variety model, I find that there are three possible steady state results. A country can either become a perpetual innovator, it can become a perpetual imitator, or it can converge to a steady state where it does a combination of both. The tractability of the model allows me to provide analytical solutions for the growth rate and TFP of each steady state, and the predicted solutions for growth and TFP are consistent with empirical results. I find that if a country can transition from imitating to innovating, it will have a higher growth rate and higher TFP. I also investigate the effect that government policy can have on growth and TFP and conclude that subsidies to R&D can increase both. I also conclude that subsidies to education and health are welfare improving.

This dissertation also investigates how government policy affects technology diffusion. Using plant-level data from Mexico, I use a fixed-effects model to research the effect that trade liberalization has on the diffusion of technology in disembodied form. The estimation strategy that was used allows me to control for plant-specific, time-invariant unobservables. The results suggest that trade liberalization not only decreases royalty payments, but it also decreases the importance of patents and licenses as a channel of technology diffusion.
Technology Diffusion, Learning from Imitation, and Growth

by

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A dissertation submitted to the Graduate Faculty of North Carolina State University in partial fulfillment of the requirements for the degree of Doctor of Philosophy

Economics

Raleigh, North Carolina

2012

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DEDICATION

To my parents: without you, there would have been no me. Thanks dad for instilling in me a love of learning. Thanks mom for your unconditional love and support. It’s nice to know that you always think that I’m the greatest! Thanks Tyson for checking out all those books for me when we were kids. Who would have guessed back then what the future had in store for me. Thanks Aunt Cup for always encouraging me, always being there when I need you, and always taking care of me. Thanks Meme for always praying for me. To my entire Bible study friends: thanks for being prayer warriors!!! To God: This would have been totally impossible without you. I am so thankful that I can do all things through Christ who strengthens me!!!
BIOGRAPHY

The author was born in Spartanburg, SC and graduated from Dorman High School. After graduation, she embarked on a global adventure that has taken her to twenty-nine countries. The author has been to South America, Europe, and Asia. She has a Bachelor’s Degree (Diplom-Kauffrau) from the University of Paderborn, Germany. She worked in Germany, Spain, and Italy before deciding that it was time to go to grad school. She first obtained a Master’s Degree in International Studies and then decided to pursue a doctorate in Economics at North Carolina State University.
ACKNOWLEDGMENTS

I extend my deepest gratitude to my parents, family and Bible study groups. Thank you, thank you, and thank you!!! I could not have gotten through the grueling demands of writing a dissertation without your love, support, encouragement, and constant prayers.

I especially would like to thank my advisor, John Seater, without whom this dissertation would not have been possible. Thank you for believing in me and my research. Thank you for your guidance. Thank you for your dedication, and thank you for helping me whenever I needed it. Thank you Asli Leblebicioğlu for teaching me the foundations of growth models and providing me with advice on how to improve my research. Thank you Pietro Peretto for your feedback, wealth of knowledge, and expertise. I would like to extend a very special thank you to Ivan Kandilov, who has provided immeasurable support for this dissertation.

Thank you Thomas Gries for being such an outstanding Professor. I decided to major in macroeconomics because of you. Thank you for all those extra help sessions you offered us. I also would like to thank every faculty member and classmate, who provided much needed help and encouragement during my years as a doctoral student at NC State University.
# TABLE OF CONTENTS

List of Tables ........................................................................................................................................ ix

List of Figures.......................................................................................................................................... x

Chapter 1 Technology Diffusion: A Catalyst for Innovation and Endogenous Growth .................. 1

1.1 Introduction ...................................................................................................................................... 1

1.2 Background and Previous Literature ............................................................................................... 3

1.3 The Model ....................................................................................................................................... 13

1.3.1 Overview and Important Assumptions ......................................................................................... 13

1.3.2 Households in Country B ............................................................................................................ 17

1.3.3 Production and Market Entry in Country B .................................................................................. 20

1.3.4 Value of the Firm and Free Entry ............................................................................................... 27

1.3.5 The Rate of Return to R&D ....................................................................................................... 27

1.4 Aggregate Dynamics ....................................................................................................................... 29

1.4.1 The Investment Decision ........................................................................................................... 29

1.4.2 The Evolution of β ....................................................................................................................... 32

1.5 General Equilibrium Results ....................................................................................................... 35

1.5.1 Steady State Results: Regime 1 ................................................................................................. 36

1.5.2 Steady State Results: Regime 2 ................................................................................................. 42

1.5.1 Steady State Results: Regime 3 ................................................................................................. 45

1.6 Empirical Implications ............................................................................................................... 47
1.7 Conclusion ...........................................................................................................50

Chapter 2 Government Intervention in the Economy .............................................53

2.1 Introduction ........................................................................................................53

2.2 Intervention in the Education (Health) Sector of the Economy ....................54

  2.2.1 Regime 1 Results with Government Intervention ..................................56

  2.2.2 Regime 2 and 3 Results with Government Intervention .......................61

2.3 Pareto Optimality and Government Intervention ..........................................63

2.4 Pareto Optimal Results vs. the Decentralized Results .................................65

  2.4.1 Regimes 1 and 3 .......................................................................................71

  2.4.2 Regime 2 ..................................................................................................71

2.5 Government Intervention ..............................................................................73

  2.5.1 Subsidies to R&D ..................................................................................74

  2.5.1 Subsidies to Manufacturing ....................................................................76

  2.5.1 Subsidies to Education and Health ......................................................77

2.6 Conclusion .......................................................................................................79

Chapter 3 The Impact of Trade Liberalization on Technology Diffusion ..............82

3.1 Introduction ......................................................................................................82

3.2 Background and Previous Literature .............................................................85

3.3 The History of Trade Liberalization in Mexico ..............................................92

3.4 The Data ...........................................................................................................95

3.5 Model and Empirical Methodology ...............................................................96
3.5.1 Estimation Model ................................................................. 96
3.5.2 Summary Statistics .............................................................. 98
3.5.3 Estimation Strategy .............................................................. 104
3.5.4 Diagnostic Tests ................................................................. 105
3.6 Estimation Results ................................................................. 107
  3.6.1 Estimation Results: All Firms ............................................. 107
  3.6.2 Estimation Results: Heterogeneity Across Firms ................. 113
3.7 Conclusion ............................................................................. 121

Bibliography ............................................................................ 126

Appendices .................................................................................. 136

Appendix A Appendix to Chapter 1 .............................................. 137
  A.1 Overview of the Model .......................................................... 137
    A.1.1 Calculating the Optimal Aggregate Demand of Intermediate Goods .... 137
    A.1.2 Calculating the Cost of Entry............................................... 138
    A.1.3 Calculating the Optimal Price that Maximizes Profit ................. 139
    A.1.4 The Rate of Return to Imitation and Innovation and the Investment Decision .......................................................... 139
  A.2 General Equilibrium Results .................................................. 140
    A.2.1 Steady State Growth Rates ............................................... 140

Appendix B Appendix to Chapter 2 .............................................. 142
  B.1 Pareto Optimality ................................................................. 142
B.1.1 Optimal Output ....................................................................................... 142

B.2 Government Intervention ........................................................................... 144

B.2.1 Subsidies to R&D.................................................................................. 144

B.2.2 Subsidies to Manufacturing................................................................. 146

B.2.3 Optimal Subsidies ................................................................................ 147

B.2.4 Optimal Value of Worker Efficiency.................................................. 148
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Patents Granted to Residents: Rank per Country</td>
<td>7</td>
</tr>
<tr>
<td>1.2</td>
<td>Conditions for Each Regime</td>
<td>31</td>
</tr>
<tr>
<td>2.1</td>
<td>Government Intervention in Regime 1</td>
<td>55</td>
</tr>
<tr>
<td>3.1</td>
<td>Tariff and License Coverage Rates</td>
<td>91</td>
</tr>
<tr>
<td>3.2</td>
<td>Summary Statistics: All Firms</td>
<td>97</td>
</tr>
<tr>
<td>3.3</td>
<td>Summary Statistics: Large Firms</td>
<td>98</td>
</tr>
<tr>
<td>3.4</td>
<td>Summary Statistics: Medium Firms</td>
<td>99</td>
</tr>
<tr>
<td>3.5</td>
<td>Summary Statistics: Small Firms</td>
<td>100</td>
</tr>
<tr>
<td>3.6</td>
<td>Estimation Results: All Firms</td>
<td>105</td>
</tr>
<tr>
<td>3.7</td>
<td>Estimation Results: Large Firms</td>
<td>113</td>
</tr>
<tr>
<td>3.8</td>
<td>Estimation Results: Medium Firms</td>
<td>114</td>
</tr>
<tr>
<td>3.9</td>
<td>Estimation Results: Small Firms</td>
<td>115</td>
</tr>
</tbody>
</table>
### LIST OF FIGURES

| Figure 1.1 | The Evolution of the Number of Patents Granted to Residents from 1995-2009 in Japan, the USA, China, South Korea, and Taiwan | 9 |
| Figure 1.2 | The Evolution of the Number of Patents Granted to Residents from 1995-2009 in Singapore, Malaysia, and Thailand | 9 |
| Figure 1.3 | The Evolution of the Number of Articles Published in Scientific Journals from Researchers in Japan, the USA, China, South Korea, and Taiwan | 10 |
| Figure 1.4 | The Evolution of the Number of Articles Published in Scientific Journals from Researchers in Singapore, Thailand, Malaysia, and Indonesia | 10 |
| Figure 1.5 | Regime 1 Dynamics | 31 |
| Figure 1.6 | Regime 2 Dynamics | 32 |
| Figure 1.7 | Regime 3 Dynamics | 32 |
| Figure 1.8 | General Equilibrium Dynamics | 37 |
| Figure 1.9 | General Equilibrium Dynamics | 43 |
| Figure 2.1 | General Equilibrium Dynamics | 56 |
| Figure 2.2 | General Equilibrium Dynamics | 58 |
| Figure 2.3 | General Equilibrium Dynamics | 61 |
| Figure 2.4 | General Equilibrium Dynamics | 61 |
| Figure 2.5 | Decentralized Result vs. the Pareto Optimal Result | 66 |
| Figure 2.6 | Decentralized Result vs. the Pareto Optimal Result | 70 |
| Figure 2.7 | Subsidizing Education and Health | 75 |
Chapter 1

Technology Diffusion: A Catalyst for Innovation and Endogenous Growth

1.1 Introduction

The empirical evidence clearly shows that some former developing countries have transitioned from reverse engineering and imitating products to inventing new products. While the transition from imitation to innovation has been addressed at the microeconomic level and researched substantially by development and industrial organization (IO) economists, no previous endogenous growth theory has adequately addressed this phenomenon. This chapter of my dissertation expands the theory of technology diffusion and endogenous growth by showing how imitation can be a catalyst for innovation in developing countries because of a process of learning to innovate. It explains how workers in a developing country learn how to innovate and develop new products after they reverse engineer a more developed country’s products. It also explains why some developing countries can transition from imitating products to inventing new products, while other countries can not.

1Throughout this chapter, learning to learn and learning to innovate are used interchangeably and refer to the same process of becoming more efficient at innovating by imitating a more advanced country’s products.
The model I develop is based on the traditional Grossman and Helpman (G-H) variety expansion model. I extend their model to include a learning to innovate effect that increases the efficiency level of R&D workers in the innovative sector of the economy. My research incorporates the current notion that the opportunity to copy an advanced country’s products and its embedded technology actually helps workers in less developed countries acquire skills that will allow them to become more productive at innovating and creating new products. This is a new strand of thought in the diffusion of technology literature at the macroeconomic level, and while similar to learning by doing, the two concepts are not identical.

Michelle Connolly and Diego Valderrama explain the difference as follows: “learning to learn differs from the more common notion of learning by doing in that the skills gained are applicable to different types of research as opposed to being limited to the exact task in which the learning occurs.” They further explain the process of learning to innovate by using the analogy of students in graduate school. When graduate students first begin graduate school, they imitate and dissect existing knowledge in their respective fields. Once students acquire knowledge that has already been disseminated, they can then invent new knowledge by conducting their own research i.e. the students have learned how to innovate.

When I incorporate a learning to innovate effect in the G-H model, I find that a developing country can transition from imitating an advanced country’s products to inventing new products. This transition occurs if the productivity of researchers, who invent new products, increases enough so that the rate of return to imitation is the same as the rate of return to innovation. When both rates are equal, firms invent new products and copy already invented products in the steady state. If workers become very productive at innovating, and the rate

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2Connolly and Valderrama (2005 p.2).
of return to innovation becomes greater than the rate of return to imitation, then firms only invest in inventing new products in the steady state. Contrary to the G-H model, with learning to innovate, there are three possible steady states: a country can become a perpetual innovator, it can become a perpetual imitator, or it can converge to a steady state where it does both.

The most important contribution this chapter of my dissertation makes to the literature is that it presents a variety expansion model that has an endogenous process for learning to innovate that is dynamic and not mechanical. The model can explain how a developing country can transition from imitating to innovating, and its predictions are substantiated by empirical research that has been conducted using actual data. A desirable property of the model is the fact that it has closed-form solutions. The tractability of the model allows me to provide analytical solutions for the growth rate and total factor productivity (TFP) of each steady state. This chapter is organized as follows: Section 1.2 provides the background and an overview of the previous literature, Section 1.3 presents the model, Section 1.4 includes an analysis of the aggregate dynamics of the economy, Section 1.5 explains the general equilibrium results, Section 1.6 explores the empirical implications of the model, and Section 1.7 concludes.

1.2 Background and Previous Literature

Current research suggests that the growth rate of a country depends on how effectively it has overcome barriers to human development and to technological innovation (Howitt and Mayer-Folkes 2004). Feyrer (2008) asserts that differences in technology are what cause differences in growth rates and dynamics across countries. Romer (1990) concludes that
“technological change lies at the heart of economic growth.” Klenow and Rodriguez Clare (1997) study the growth rates of productivity across countries and conclude that productivity differences account for 91% of the difference in growth rates of output per worker. Both authors assert that models that emphasize the accumulation of human capital as a catalyst for growth overstate its importance.

They also conclude that endogenous growth models should incorporate technology diffusion and policies that affect productivity in order to research differences in growth rates across countries. The research done by Easterly and Levine (2001) further substantiate the findings of Klenow and Rodriguez Clare. They conclude that factor accumulation is not sufficient for explaining why countries have different growth rates of GDP per capita. Easterly and Levine use the Penn-World Tables to assert that the growth of total factor productivity (TFP) accounts for 60% of the growth of output per worker. They state that future research needs to focus not only on studying why productivity differences across countries exist, but also on defining TFP more precisely and modeling how technology diffuses from one country to another country.

These findings confirm the importance of developing theoretical models that explain how technology diffuses from an advanced country (that is more productive in researching and developing new products) to a country that is less developed and inefficient in researching and developing new products. Grossman and Helpman (1991b) have often been credited with proposing the very first endogenous growth model of technology diffusion. Their model is truly novel because they endogenize the decision to invest in innovation or imitation instead of making it exogenous like earlier growth models had done.

Some of the most well known growth models of technology diffusion are variations of
the Grossman and Helpman model.\textsuperscript{3} Other economists have used the Nelson and Phelps (1966) model that incorporates human capital to research technology diffusion. At times international trade is the conduit for technology diffusion. The Connolly (1997), Connolly and Valderrama (2005), Coe, Helpman and Hoffmaister (2008), Eaton and Kortum (2002), and Xu and Chiang (2005) models follow this approach. Eaton and Kortum (1996,1999), Xu and Chiang (2005), and Guellec and van Pottelsberghe (2003) assume that technology can be transferred from one country to another without trade. They use data on patents and the stock of R&D capital to study technology diffusion. Xu and Chiang (2005) also use the Nelson and Phelps model to study how technology diffuses in disembodied form.\textsuperscript{4}

Some of the research findings concerning the diffusion of technology have concluded that when trade exists, the less developed country will have a comparative advantage in low-technology goods while more developed countries will have a comparative advantage in goods that are produced with a high level of technology (Lucas 1998, Boldrin and Scheinkman 1988, and Matsuyama 1992). The research of other economists, who have studied the diffusion of technology conclude that the less developed country will be a perpetual imitator forever (Grossman and Helpman 1991a, 1991b, 1991c, Aghion and Howitt 2008, Barro and Sala-i-Martin 2004). The extension of the Barro model allows for innovation in the less developed country, but then it has the unrealistic conclusion that the more developed country will stop innovating and start copying the newly invented goods from the less developed country that has now become the more advanced country. The shortcomings of these mod-

\textsuperscript{3} Keller (2004) offers an excellent survey of the research that has been conducted concerning international technology diffusion and its effects on productivity.

\textsuperscript{4} According to eurostat, “the acquisition of disembodied technology includes acquisition of external technology in the form of patents, non-patented inventions, licenses, disclosure of know-how, trademarks, designs, patterns and computer and other scientific and technical services related to the implementation of TPP innovations, plus the acquisition of packaged software that is not classified elsewhere.” This definition can be found at www.eurostat.ec.europa.eu
els are that they do not allow for a learning process that can help the less developed country learn to innovate when the data shows that some former less developed Asian countries have become technology innovators.

Figures 1.1 and 1.2 illustrate the fact that the number of patents granted per resident in Japan, China, the USA, South Korea, Taiwan, Singapore, Malaysia, and Thailand was higher in 2009 than in 1995. The World Intellectual Property Organization (WIPO) defines patents as an “an exclusive right granted for an invention, which is a product or a process that provides, in general, a new way of doing something, or offers a new technical solution to a problem.” This definition is taken from the WIPO website http://www.wipo.int/patentscope/en/.

The WIPO website also offers the following explanation for how a patent is granted and what constitutes an invention: “an invention must, in general, fulfill the following conditions to be protected by a patent. It must be of practical use; it must show an element of novelty, that is, some new characteristic which is not known in the body of existing knowledge in its technical field. This body of existing knowledge is called prior art. The invention must show an inventive step which could not be deduced by a person with average knowledge of the technical field. Finally, its subject matter must be accepted as patentable under law. In many countries, scientific theories, mathematical methods, plant or animal varieties, discoveries of natural substances, commercial methods, or methods for medical treatment (as opposed to medical products) are generally not patentable.”

Based on this definition, and evaluating the data in both figures, it is evident that Japan, South Korea, Taiwan, and China are examples of countries where firms have successfully transitioned from imitating to innovating, while firms in Malaysia, Singapore, Thailand,

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5I decided to use the data on patents granted instead of patent applications as a proxy for innovation because the actual granting of a patent to an inventor implies that the product or process was truly novel.
and Indonesia are increasing their efforts to innovate. Table 1 lists each country’s rank with regard to patents granted in 1995 and 2009. The extent of innovation in each country is made even more apparent by this data. Even though Thailand, Singapore and Malaysia have fewer patents granted than Japan, South Korea, China, and Taiwan, each country’s rank has increased substantially since 1995.

Table 1.1 Patents Granted to Residents: Rank per Country

<table>
<thead>
<tr>
<th>Country</th>
<th>Rank in 1995</th>
<th>Rank in 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Taiwan</td>
<td>17</td>
<td>5</td>
</tr>
<tr>
<td>Japan</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>China</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>South Korea</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Thailand</td>
<td>83</td>
<td>50</td>
</tr>
<tr>
<td>Singapore</td>
<td>64</td>
<td>25</td>
</tr>
<tr>
<td>Malaysia</td>
<td>59</td>
<td>34</td>
</tr>
</tbody>
</table>

Source: WIPO and National Statistics of the Republic of China

Figures 1.3 and 1.4 show the evolution of the number of articles published in scientific journals from 1985 to 2007 by authors residing in China, Japan, Taiwan, South Korea, Thailand, Malaysia, Indonesia, and Singapore. If it is assumed that these published articles reflect the level of activity dedicated to innovating in each country, then one can conclude that research aimed at inventing new products, processes or ways of solving problems has increased since 1985. Carolan, Singh, and Talati (1997) research bilateral trade between the US and Hong Kong, Indonesia, Japan, Korea, Malaysia, Singapore, Taiwan and Thailand from 1962-1992 and discover that the trade patterns between the US and these eight countries has changed during this time period. In the beginning, these East Asian countries exported low-level technology goods to the US. From 1962-1992, each country’s compara-
tive advantage changed so that by 1992, they were exporting technologically sophisticated goods to the US. The data from the World Competitiveness Yearbook (2002, 2009) also indicates that South Korea, China, Malaysia, Taiwan, Singapore, and the Philippines are currently manufacturing high-tech goods.\textsuperscript{6}

\textsuperscript{6}\textit{This observation of the World Competitiveness data was made by Amy Glass (2010).}
Figure 1.1 The evolution of the number of patents granted to residents from 1995-2009 in Japan, the USA, China, South Korea, and Taiwan. Source: World Intellectual Property Organization (WIPO). Taiwan data source: National Statistics of the Republic of China.

Figure 1.2 The evolution of the number of patents granted to residents from 1995-2009 in Singapore, Malaysia, and Thailand. Source: WIPO.
Figure 1.3  The evolution of the number of articles published in scientific journals from researchers in Japan, China, South Korea, and Taiwan. Source: World Development Indicators (WDI). Taiwan data source: National Statistics of the Republic of China.

Figure 1.4  The evolution of the number of articles published in scientific journals from researchers in Singapore, Thailand, Malaysia, and Indonesia. Source: World Development Indicators (WDI).
Development economists have researched technology diffusion within the newly industrializing economies (NIEs)\(^7\) and concluded that there has been a definite transition from imitation to innovation. Nelson and Pack (1999) suggest that South Korea, Taiwan, Singapore, and Hong Kong used the knowledge acquired through absorbing knowledge from abroad to learn how to innovate. Both authors assert that technology diffusion was instrumental in increasing the productivity of labor and providing workers with the skills needed to invent new products. Hobday (1995) also proposes that a learning to innovate process exists, and its success (firms begin to innovate) depends on the resources firms allocate to the learning process. He contends that not only do firms absorb advanced knowledge from abroad in order to increase productivity, but they also use the acquired knowledge to learn how to invent new products. Lall (1987) also investigates the learning to innovate\(^8\) process in India.

At the macroeconomic level, current research is starting to address the issue that some countries (that used to be technology imitators) are now technology innovators. New models are being developed to explain how this process occurred. The general consensus is that the catalyst for innovation was the diffusion of technology, and the learning process associated with it. Rachel van Elkan (1996) develops the first (endogenous growth) diffusion of technology model that allows for a transition from imitation to innovation in the less developed country. Her model includes a learning from imitation effect and a learning by doing effect

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\(^7\) Kim and Nelson (2000) contains articles that provide an excellent overview about how firms in NIEs have managed to transition from imitation to innovation. Kim (1997) investigates how firms in South Korea managed to learn how to innovate.

\(^8\) Lall refers to learning to innovate as learning to industrialize. He also refers to technology diffusion as the acquisition of technological capability. He focuses on India’s acquisition of technological capability in three industries.
of innovation that augments human capital. She finds that imitator countries can eventually become product innovators once human capital increases enough through imitation, and the rates of return to both activities become equalized. van Elkan rules out complete specialization and concludes that LDCs will innovate and imitate in the steady state. van Elkan’s model does not include a formal R&D sector which is somewhat unrealistic for a model of technology diffusion. The consensus is that while it is important to have an educated workforce, it is the R&D that is conducted within a LDC that is critical for the successful assimilation of technology from abroad.

Michelle Connolly (1997) also researches the idea of learning to innovate. In her 1997 paper and subsequent 2005 paper with Diego Valderrama, she presents the concept of learning to learn. Both authors assert that technology diffusion begins as the producers in the follower countries use knowledge gained through past imitation to improve the quality of the leader’s products and eventually overtake the leader’s quality with new quality inventions of their own (vertical innovation). Currie, et. al (1999) is the first variety expansion model that incorporates the possibility of innovation in a LDC. Their model investigates how cost reducing knowledge spillovers influence the decisions of firms in less developed countries. They have three possible steady state regimes in their model: imitation in the LDC with innovation in the more developed country; imitation and innovation in the LDC with innovation in the more developed country; and innovation in the LDC with innovation in the more developed country. The transition between steady states is mechanical and not dynamic. Amy Glass (2010) also studies the learning through imitation effect, and her quality ladder model includes the possibility for innovation by LDCs. Her model does not specifically develop an endogenous process of learning to learn that enables firms to become more efficient at innovating than imitating.
1.3 The Model

1.3.1 Overview and Important Assumptions

The model presented in this dissertation characterizes how technology diffuses from a leader country to a follower country when there is no international trade in goods and services. An example of a leader country (henceforth referred to as country A) is the United States. An example of a follower country (henceforth referred to as country B) is China. Country A is superior to country B with respect to productivity and product innovations. Country A is also good at research and development, inventing new products and incorporating new ideas and technological advancements into the production process. Mansfield et al. (1981) find that it is cheaper to imitate than innovate in terms of cost and effort. In keeping with their results, it is assumed that in the beginning, it is cheaper and more efficient for a producer in country B to imitate country A’s technology and products than to try to develop cost cutting measures and new products.

It is assumed that technology can flow from one country to another without trade. Even though international trade is clearly an important channel for technology diffusion, it is not the only channel. Eaton and Kortum (1996,1999), and Xu and Chiang (2005) show that international patents are a channel whereby technology diffuses. Xu and Chiang find that middle-income and low-income countries benefit substantially from foreign patents. Guellec and van Pottelsberghe (2003) assume that technology can be transferred from one country to another without trade. They find that both domestic and foreign R&D capital stocks affect long term productivity. Mansfield and Romeo (1980) also study the means by which technology diffuses from one country to another. Their research shows that most
managers at US based firms were convinced that reverse engineering was the main channel of technology transfer to foreign firms. Managers also believed that the information obtained by patents and foreign companies recruiting and subsequently hiring their workers also contributed to technology diffusion. Other channels of technology diffusion include foreign direct investment (FDI) and sending students/managers abroad to study.\textsuperscript{9}

For the purposes of this chapter, it is assumed that technology diffuses from country A to country B whenever entrepreneurs in country B decide to obtain a copy of a product that has been invented in country A in order to give it to researchers located in their country. These researchers will then reverse engineer each product and make it available for production in country B. The reason why I opt for reverse engineering as the channel of technology diffusion is because of the idea of tacit knowledge. Evenson and Westphal (1995) explain how important the transfer of tacit knowledge is to increasing productivity. Both authors assert that tacit knowledge “can only be acquired through investments in learning-learning that is importantly grounded in purposeful analysis of information gained through practical experience. With learning comes increased understanding of technology and of circumstances, which typically results in changes away from the original solution, as techniques are adapted to local circumstances or otherwise modified to achieve higher productivity. Learning is generally a sequential process, so that alterations in techniques usually take place through a progression of problem reformulations leading to new solutions (p. 2214).”

Tacit knowledge is transferred to R&D workers in a developing country during the process of reverse engineering. During this process, researchers disassemble technologically

\textsuperscript{9}The most well-known example of this type of technology diffusion is the case of Eiji Toyoda (Weil 2009). Toyoda spent two month’s observing and learning at Ford’s technologically advanced automobile factory in Michigan. He later returned to Japan and successfully used what he learned when he opened his own company: Toyota.
advanced products, and they have to figure out how to adapt the products for use in their country. They also learn how to correctly reassemble each product and its embedded technology. Thus, as the research indicates, it is not just exposure to advanced products that increases productivity, but it is the transfer of tacit knowledge and the increase in worker efficiency\(^\text{10}\) that substantially increases productivity. Since I postulate that R&D workers in country B learn how to innovate from imitation, reverse engineering is the most appropriate channel of technology diffusion to use. As R&D workers in the LDC reverse engineer country A’s more technologically sophisticated products, they increase their analytical and critical thinking skills as well. If they increase their skill set sufficiently enough, they will learn how to innovate new products. Evenson and Westphal agree with this logic of how learning to innovate occurs. Both authors assert that “investments in learning lead either to assimilation, duplicating understanding that exists elsewhere without adding to the stock of reproducible technology, or to invention and innovation, adaptive or otherwise, creating novel elements of reproducible technology that yield higher productivity under local conditions (p. 2214).”

There are no international financial markets, and there is no exchange of goods, services, or labor between country A and B. It is assumed that it is the knowledge that is inherent in the goods, and not the process of importing goods, that promotes the diffusion of technology. If firms in country B purchase just one product that has been invented in country A, reverse engineer it, copy it, manufacture it, and sell it themselves within their country, then technology diffusion occurs.

The novel feature of my model is the fact that imitation of a leader country’s products increases the productivity of labor in the follower country. Although the basic framework

\(^{10}\)Nelson and Pack (1999) and Hobday (1995) explain this fact in more detail.
is that of the classic Grossman and Helpman (G-H) set-up of product innovation, the ad-
ddition of this feature is an important modification of their model. The production function
for each firm is the same as the one used in the G-H model. Their model does not include
the concept of learning to innovate which is what I want to investigate. Because of this,
I have modified their baseline model with respect to how the number of product varieties
grows and added a learning to innovate effect. This allows me to research the effect that
technology diffusion has on production, costs, and growth. I have opted to use the same
case of learning to innovate that was first introduced in the van Elkan (1996) Connolly
(1997) models; however, I have modeled this process differently. I incorporate a knowledge
spillover effect that not only increases the productivity of researchers assigned to imitate
country A’s goods as the number of imitated goods increases in country B, but it also in-
creases the productivity of researchers assigned to invent new products. This captures the
effect of learning to innovate.

Producers in country B decide if they want to copy country A’s product or invent their
own product. When the decision to imitate is made, a copy of country A’s product is obtained
and reverse engineered. Contrary to the Barro and Sala-i-Martin (2004), Aghion and Howitt
(2009), Acemoglu (2009), and G-H (1991b) models, firms in country B are not imitators
indefinitely. Because imitation raises the productivity of labor in country B, increases the
general knowledge level within the country and increases the skill-set of the labor force, at
some point, it might become advantageous for firms in country B to start innovating. Once
innovation becomes profitable, firms stop imitating and start developing new products and
technologies. The number of goods that can be copied in country B depend on the number
of goods that have already been invented in country A. Firms that imitate goods pay no fees
to the foreign inventor. Once a firm copies a product, it becomes the monopoly provider,
and the remaining firms can only copy the subset of country A’s goods that have not been copied already. Imitation takes place when a firm in country B copies a product that is new only to country B. Innovation takes place when a firm invents a product that is new to the world.

1.3.2 Households in Country B

Households in country B are analogous to the set-up in G-H (1991c). There are \( L \) identical households that supply labor and consumption loans in competitive markets. Labor is supplied inelastically by each household, and each household is endowed with one unit of labor. There is no population growth. The representative household maximizes lifetime utility

\[
U = \int_{0}^{\infty} e^{-(\rho)t} \log C_t dt, \quad \rho > 0
\]

subject to the flow budget constraint

\[
\dot{A} = Ar + w - E
\]

\( \rho \) is the individual discount rate, \( A \) is assets holding, \( r \) is the rate of return on assets, \( w \) is the wage rate, and \( E \) is consumption expenditure. Profits are distributed equally to consumers, and all variables are in per capita terms. To simplify the notation, time subscripts for endogenous variables are suppressed whenever confusion does not arise. As usual, the functional form used for utility is increasing in \( C \) and is concave i.e. \( U'(C) > 0 \) and \( U''(C) < 0 \). The utility function also satisfies the Inada conditions: \( U'(C) \to \infty \) as \( C \to 0 \), and \( U'(C) \to 0 \) as \( C \to \infty \). The consumption index C:
C = \left[ \int_0^{N_B} C_i^{(\eta-1)/\eta} \, d_i \right]^{\eta/(\eta-1)}, \, \eta > 1 \quad (1.2)

is interpreted by using Ethier’s (1982) definition and reflects the fact that total factor productivity (TFP)\textsuperscript{11} rises with the number of available varieties (G-H 1991). C represents a final good that is consumed by each household. $C_i$ denotes the input of intermediate good or service $i$ into production of the final good, so every $C_i$ is a differentiated intermediate good. $\eta > 1$ is the elasticity of product substitution. $N_B$ is the number of goods (firms) existing at time $t$. It also represents the knowledge stock that is available at time $t$. The Lagrangian for calculating $C_i \equiv X_i = L \cdot C_i$ is

$$L = \left[ \int_0^{N_B} C_i^{(\eta-1)/\eta} \, d_i \right]^{\eta/(\eta-1)} + \lambda \left[ E - \int_0^{N_B} P_{iX} C_i d_i \right] \quad (1.3)$$

Where $P_{iX}$ is the price of the good $X_i$. Using the FOCs for $\frac{\partial L}{\partial C_i}$, and the fact that $E = \int_0^{N_B} P_{iX} C_i d_i$ yield

$$C_i = E \left[ \frac{P_{iX}^{-\eta}}{\int_0^{N_B} P_{jX}^{1-\eta} \, d_j} \right] \quad (1.4)$$

where $C_i$ represents the optimal input of good $i$ into the production of the final good $C$.

The optimal aggregate demand of $C_i \equiv X_i = L \cdot C_i$ is

$$X_i = LE \left[ \frac{P_{iX}^{-\eta}}{\int_0^{N_B} P_{jX}^{1-\eta} \, d_j} \right] \quad (1.5)$$

\textsuperscript{11}TFP = N_B^{1/(\eta-1)}
Consumers demand equal amounts of each good because they love product variety, but they are indifferent as to how they obtain this variety. Consumers view imitated goods as imperfect substitutes for innovated goods. The fact that an increase in product variety also increases utility, leads to symmetric demand functions for each good. Because of this, the choice of which type of good (imitated or innovated) to produce will be made at the firm level as managers seek to maximize profit and obtain the highest return on their investments. The current valued Hamiltonian for the consumer’s dynamic optimization problem is:

\[ H_c = \log C_t d_t + \mu (A_t + w - E) \]  

(1.6)

with the transversality condition:

\[ \lim_{t \to \infty} \mu_t A_t e^{-\rho t} = 0 \]  

(1.7)

Using the fact that \( C = \frac{E}{\rho} \) the FOCs for \( \frac{\partial L}{\partial C} \) and \( \frac{\partial L}{\partial A} \) the optimal expenditure plan is the well known Euler equation

\[ \frac{E}{E} = (r - \rho) \]  

(1.8)

Prices are normalized in order to make nominal spending constant. This means that \( E_t = 1 \), and \( r_t = \rho \) for all \( t \).

\(^{12}\)While some models assume that new products are introduced into the economy because of changes in consumer demand, I assume that new products are developed when entrepreneurs decide that it is profitable for them to do so. Benavente (2006) concludes that in Chile “technology push indicators are much stronger than demand pull elements” on the decision of firms to innovate. He also suggests that this should be typical for most LDCs.
1.3.3 Production and Market Entry in Country B

Producers in country B produce one differentiated consumption good according to the following production function:

\[ X_i = L \times i \]  \hspace{1cm} (1.9)

\( X_i \) is one unit of output, and \( L \times i \) is labor employment in production i.e. one unit of labor produces one unit of output.\(^{13}\) Production of each good \( X_i \) is the same for all firms because of the symmetric equilibrium\(^{14}\). Before a firm can produce the amount of a good that is demanded by consumers, an entrepreneur in country B has to choose between either using R&D to develop a new, differentiated product and manufacturing process or to purchase, reverse engineer and imitate a differentiated product and manufacturing process from country A. This is the market entry decision. In the beginning, entrants prefer to copy country A’s products and then adapt them for use in country B is because it is more cost effective and efficient. The novel feature of this model is that imitation of country A’s products increases the productivity of R&D workers in the innovation sector of the economy in country B.

Entrepreneurs in country B are searching for new markets and are somewhat risk averse. Imitation cuts down on marketing and lowers the risk that the new firm will not work. Entrepreneurs internalize the fact that if a firm was successful in country A, it has a high probability of also being successful in country B. They also internalize the fact that entrepreneurs have already done the market research for them and found which sectors are profitable. This is what makes imitation appealing, and initially entrants prefer to reverse engineer products from country A than invent their own products.

\(^{13}\)To simplify the notation, I suppress the time arguments throughout the rest of this chapter.
\(^{14}\)This symmetric equilibrium will also lead to symmetric prices for each good and symmetric wages
The main reason why imitation is so appealing at first is the fact that with imitation, there is an increase in productivity as R&D workers, who now have access to the technology of country A, can increase their own skill set. As the workers increase their skill set, they learn how to think and invent new products and technologies themselves. The incentive to invent new products exists because imitation lowers the entry cost of innovation, and it increases the return to R&D aimed at inventing new goods. The entry technology is characterized by two different equations based on whether a good is imitated or invented:

\[
\dot{M} = \alpha(\bar{S}, \bar{H})N_BL_M, \alpha > 0\tag{1.10}
\]

\[
\dot{N} = \beta(M, \bar{S}, \bar{H})N_BL_N, \beta(M) > 0\tag{1.11}
\]

\[
\frac{N_B}{N_B} = \frac{M}{N_B} + \frac{N}{N_B}\tag{1.12}
\]

where \(L_M\) is the aggregate amount of labor devoted to R&D\(^{16}\) aimed at reverse engineering country A’s products, and \(L_N\) is the aggregate amount of labor devoted to R&D aimed at inventing new products. \(M\) always represents a good that has been reverse engineered, and the total number of imitated goods available in country B is always a subset of the total number of goods that have already been produced and invented in country A.\(^{17}\) The total number of product varieties available in country B is \(N_B = N + M\). In the beginning, \(\alpha > \beta\), and represents the fact that copying is easier than innovation for the initial stock of knowledge capital. This means that country B starts out by copying country A’s products because

\(^{15}\)N \equiv \text{invented technology that is new to the world and M \equiv imitated technology that is only new to country B.}\n
\(^{16}\)The importance of firm level R&D efforts for technology diffusion is researched in Hu et al. (2005). The authors analyze firm level data in China and find that technology diffusion occurs and is most effective when firms in China actively engage in R&D. Actively engaging in R&D makes it easier to absorb outside knowledge.

\(^{17}\)This means that if \(N_A \equiv \text{the total number of product varieties available in country A, then } M \subset N_A\).
workers are more productive at reverse engineering products than they are at inventing new products. The parameter $\beta$ is a function of $M, \bar{S}, \bar{H}$ and evolves as follows:

$$\beta(M) = a - be^{-M}$$

(1.13)

$$\dot{\beta} = Mbe^{-M}$$

(1.14)

$\beta(M)N_B$ and $\alpha N_B$ represent the productivity of labor in R&D. Based on equations (1.10) and (1.11), it can be noted that the knowledge spillover effect is not the same for invented and imitated goods. The reason for this is that the model has an inherent learning to innovate effect which implies that imitation not only increases the stock of public knowledge ($N_B$), but it also increases the ability of R&D workers who innovate ($\beta$). Since it is assumed that knowledge is public; therefore, making it non-rival and non-excludable, each invention (imitation) of a new product variety increases the stock of public knowledge. As the stock of public knowledge increases, and ideas and methods are disseminated, it increases the productivity of labor in R&D that is aimed at both imitation and innovation.

The functional form for $\beta$ ($\beta \equiv b - ae^{-M}$) not only represents how far country B is from the technology frontier of country A, but it also represents how efficient R&D workers can be at innovating if they are exposed to the new technology that is embedded in imitated goods. Unlike the increase in productivity that results from an increase in public knowledge, $\beta$ increases as country B approaches the technology frontier of country A. The increase in $\beta$ occurs because there is a second spillover effect of the knowledge capital that is private and only helps to increase the ability of R&D workers to innovate. While the dissemination of

\[18\] It is assumed that when the economy starts out, $M(0) \geq 1$ and $N(0) = 0$. In keeping with Barro and Sala-i-Martin (2004), it is just accepted, but not explicitly explained how country B learned how to imitate at least one good.

\[19\] for ease of exposition, the (M) is dropped from $\beta(M)$, so that $\beta(M) \equiv \beta$
ideas and methods makes future imitation and innovation easier, the actual increase in skills
that occurs because of the reverse engineering process is only beneficial to R&D workers in
the innovation sector of the economy because it increases each worker’s tacit knowledge of
how to innovate. In essence, labor productivity is composed of two parts: technology and
efficiency (tacit knowledge).

Technology in my model is represented by $N_B$ and encompasses the knowledge about
how to produce output, while $\beta$ and $\alpha$ are variables that represent how efficient researchers
are. Both variables depend on the mean education level of the workforce ($\bar{S}$) and the life
expectancy at birth of the workforce ($\bar{H}$), which reflects the health of the workforce. The
distinction between technology and efficiency is clarified by David Weil. Weil defines tech-
nology\(^{20}\) as “the knowledge about how factors of production can be combined to produce
output,” and efficiency as measuring “how effectively given technology and factors of pro-
duction are actually used” (276). Weil also defines efficiency as “an umbrella concept used
to capture anything that accounts for differences in productivity other than differences in
technology” (276). For the purposes of this paper, the former definition of efficiency is
used. It is also assumed that a worker’s health and education affects his or her efficiency
level\(^{21}\). This is the novel feature of my model: the learning to innovate effect which is
captured by $\beta$.

$\beta$ can differ across countries and increases as the number of imitated varieties increases
because reverse engineering and imitating products increases the efficiency of R&D workers
who invent new goods, but it does not increase the efficiency of workers who imitate country
A’s goods. Reverse engineering a more advanced country’s products stimulates critical

\(^{20}\)For the purpose of this dissertation, technology is embedded in capital goods and is represented by each
new product variety.

\(^{21}\)These assumptions are substantiated by the literature.
thinking and the invention of new products by R&D workers in the developing country. This means that R&D workers become more efficient at combining factors of production together to produce products that they have invented, but they do not become more efficient at reverse engineering products that have been invented by someone else in country A.

Differences in $\beta$ occur because of differences in average education levels and the average health of workers that affect the values of $b$ and $a$. For example, if a country has a healthy workforce and a high education level, then it should have a higher $a$ and a lower $b$ than a country with unhealthy workers and a low education level. The value of $b$ reflects how much reverse engineering and imitating country A's products can help increase the ability of workers to innovate, while the value of $a$ reflects the rate at which researchers in country B benefit from reverse engineering and learning to learn. The value of $a$ also reflects how far away country B is from the technology frontier of country A.

For the purpose of this chapter, it is assumed that the economy starts out with given values of $a$ and $b$ i.e $\bar{S}$ and $\bar{H}$ that won’t change overtime. An analysis of what changes to $a$ and $b$ (changes in education and health) mean to a developing country and its ability to transition from imitation to innovation is given in chapter 2. This means that (13) illustrates how much reverse engineering and imitation helps workers learn how to innovate given the initial characteristics of the workforce and the initial level of technology that is available in the economy. The fact that the ability of R&D workers (to innovate) increases as the number of imitated goods increases, is the key to understanding how the model works. This increase in worker ability increases the productivity of innovation based R&D, lowers the cost of innovation, and can make it possible for a country to transition from imitation to

---

22Essentially, $\alpha$ is a parameter and $\beta$ is a variable that changes with the number of imitated product varieties.
innovation.\footnote{Because of this, there are three possible steady state results. A country can either become a perpetual innovator. It can become a perpetual imitator, or it can converge to a steady state where it does a combination of both innovation and imitation. The conditions that lead to each result will be discussed in more detail in Section 1.4.}

In my model, the transition from imitation to innovation occurs because of a learning process that increases productivity and lowers the cost of innovation. As innovation becomes cheaper, firms have an incentive to innovate. It is not a mechanical process like the one in the Currie model. In their paper, the transition from imitation to innovation occurs only after the authors assign different values to certain parameters. The Glass model of switching from imitation to innovation is also mechanical. She assumes that government intervention influences the investment decisions of firms, and this is what drives the decision to innovate or imitate. I have developed a coherent model of learning to innovate that is not mechanical and has closed-form solutions.

The cost of acquiring the product from country A, reverse engineering it and researching the knowledge that is embedded within it “entails a lump-sum outlay”\footnote{Barro and Sala-i-Martin p. 353} which is equal to the entry cost $P_{M_i}$. Once a firm has successfully imitated a good, it becomes the monopoly provider of that good in country B. Equation (1.10) characterizes the flow of new products when an entrant uses imitated knowledge; whereas, equation (1.11) characterizes the flow of new products when an entrant uses innovated knowledge. Entrepreneurs in country B begin to copy country A’s technology because they realize that the knowledge that is available to them within their own country is insufficient for inventing new products and services.

Firms learn that they can easily acquire more advanced technology from country A, and this is what they do. In the beginning because it is cheaper to copy and adapt the technology from a leader country, the follower country only imitates and reproduces the production pro-
cess that has already been invented in the leader country. As workers learn how to innovate by imitating country A’s technology, it can become more efficient for firms to start innovating as the productivity of R&D workers increases. Once firms have successfully invented a good, they pay the entry cost $P_{Ni}$ and become the monopoly provider of that good in country B.

1.3.4 Value of the Firm and Free Entry

Using equations (1.10) and (1.11), the free entry condition for each type of firm can be calculated. The price of starting a new firm using imitated knowledge is $P_{Mi} = \frac{w}{\alpha N_B}$, and $P_{Ni} = \frac{w}{\beta N_B}$ for a firm that uses invented knowledge. Therefore, the stock market value of the firm at time $t$ is equal to the net present value of profit at time $t$ and is given by:

$$v_i(t) = \int_t^\infty \exp \int_s^t r(s) \, ds \, \pi_i(\tau) \, d\tau$$

(1.15)

$$v_{Mi} = \frac{w}{\alpha N_B}$$

(1.16)

$$v_{Ni} = \frac{w}{\beta N_B}$$

(1.17)

where equation (1.16) equates the value of the firm that uses imitated knowledge to its cost, and equation (1.17) equates the value of the firm that uses innovated knowledge to its cost.\(^{25}\)

In the beginning, $v_{Ni} > v_{Mi}$, but as $M$ increases, $\beta$ and $N_B$ increase and $v_{Ni}$ and $v_{Mi}$ decrease. The changing value of $\beta$ will determine whether a firm decides to invest in R&D aimed at innovating, imitating, or both.

---

\(^{25}\)This means that only interior solutions for the growth rate of the number of varieties are considered. The possibility for there to be no R&D or unbounded R&D in the economy are ruled out. Which type of R&D firms decide to invest in is explained in section 1.4.1 and the appendix.
The Rate of Return to R&D

The standard asset pricing equation for the rate of return to R&D is

\[ r = \frac{\pi_i}{v_i} + \frac{\dot{v}_i}{v_i} \tag{1.18} \]

\(v_i\) is defined in equations (1.16) and (1.17), and \(\pi_i = P_{iX}X_i - wX_i\). Substituting for \(X_i\) and maximizing \(\pi_i\) with respect to \(P_i\) yields the pricing strategy that maximizes profit

\[ P_{iX} = \frac{w\eta}{(\eta-1)} \tag{1.19} \]

Where \(P_{iX}\) is the monopoly price that each producer charges for each intermediate good.

Using equation (1.19), per brand operating profit is

\[ \pi_i = \frac{LE}{\eta NB} \tag{1.20} \]

Using equations (1.18) - (1.20) yields

\[ r_M = \frac{\alpha LE}{\eta w} + \frac{\dot{v}_{Mi}}{v_{Mi}} = \rho \tag{1.21a} \]

\[ r_N = \frac{\beta LE}{\eta w} + \frac{\dot{v}_{Ni}}{v_{Ni}} = \rho \tag{1.22a} \]

Where (1.21a) represents the rate of return to R&D directed at imitating country A’s goods, and (1.22a) represents the rate of return to R&D directed at innovating new goods. The rate of return to R&D is equal to the profit rate plus (minus) the capital gain (loss) derived from
the change in the value of the firm. Increases in productivity cause the rate of return to R&D to increase because it lowers entry costs. The returns to both types of R&D are decreasing with the growth rate of the number of varieties that are invented and imitated. This is due to the spillover effect of knowledge. As entry increases, the pool of knowledge available to all the firms in the market increases; therefore decreasing the returns to both forms of knowledge. This decrease in profits, which occurs as more firms enter the market and the average firm size decreases, is exactly offset by the decrease in the cost of variety expanding innovation due to the knowledge spill-over effect. This is what allows for perpetual, self-sustained growth along the BGP. It can be noted by looking at both equations that the rate of return to R&D for imitation is higher than the rate of return to R&D aimed at innovating in the beginning, but over time, as $\beta$ increases and $\frac{\beta}{p}$ decreases, the possibility exists for both rates of returns to equalize, or for the rate of return to innovation to be greater. The no arbitrage condition requires that the rate of return on a riskless asset be equal to the rate of return to R&D.

\[26 \frac{\beta}{p} \text{ decreases and asymptotically will be equal to zero.}\]

\[27 \text{ This means that if innovation is more profitable than imitation, then } r = r_N. \text{ If imitation is more profitable than innovation, then } r = r_M.\]
1.4 Aggregate Dynamics

1.4.1 The Investment Decision

The number of imitated and innovated goods that are available to consumers is decided at the firm level as managers choose which type of R&D they want to invest in. Each firm wants to maximize profit and will devote resources to R&D aimed at imitating goods or inventing new goods based on a comparison of the rate of returns to both types of R&D. My model differs from the typical endogenous growth model because it does allow for arbitrage in the assets market. It is this arbitrage possibility that determines whether firms invest in imitation or innovation.

The standard asset pricing equation for the rate of return to R&D is $r = \frac{\pi_i}{v_i} + \frac{\dot{v}_i}{v_i}$. Using the fact that $\pi_i = P_iX_i - wX_i$ and $P_iX = \frac{w}{\eta - 1}$, profit reduces to $\pi_i = \frac{LE}{\eta N_B}$. Substituting for $v_M = \frac{w}{\alpha N_B}$ and $v_N = \frac{w}{\beta N_B}$ the rate of return to imitation and innovation respectively is

$$r_M = \frac{\alpha LE}{\eta w} + \frac{w}{w} - \frac{N_B}{N_B} = \rho \quad (1.21b)$$

$$r_N = \frac{\beta LE}{\eta w} + \frac{w}{w} - \frac{N_B}{N_B} - \frac{\dot{\beta}}{\beta} = \rho \quad (1.22b)$$

As can be seen from (1.21b) and (1.22b), as long as $\beta$ evolves over time and is always less than $\alpha$, the rate of return to R&D that is aimed at imitating goods is higher than the rate of return that is aimed at inventing new goods. This means that entrepreneurs choose to enter the market as imitators only in the steady state. If $\alpha = \beta$ asymptotically, $\frac{\dot{\beta}}{\beta} = 0$, and the rate of return to both types of R&D are equal. This means that firms will invest in both types of R&D in the steady state. Firms choose to enter the market as inventors once
\[ \alpha + \frac{\delta \eta_w}{LE} = \beta \]  

(1.23)

\( \delta \) is the value of \( \frac{\dot{\beta}}{\beta} \) that occurs right before firms decide to shut down investment in imitation. This means that \( \beta > \alpha \) for innovation to take place in the steady state. Using this information, it is apparent that there are three possible growth regimes: the economy in country B can evolve over time and end up on a stable balanced growth path (BGP) with firms who specialize in imitating; the economy in country B can evolve over time and end up on a stable BGP with firms who specialize in innovating; or the the economy in country B can evolve over time and end up on a stable BGP with firms who specialize in both imitation and innovation. The conditions that lead to each growth regime are given in table 1.2.

**Table 1.2 Conditions for Each Regime**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Regime 1</th>
<th>Regime 2</th>
<th>Regime 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha &gt; \beta )</td>
<td>( \alpha + \frac{\delta \eta_w}{LE} = \beta )</td>
<td>( \alpha = \beta ) asympt</td>
<td></td>
</tr>
<tr>
<td>Rate of Return</td>
<td>( r_M &gt; r_N )</td>
<td>( r_M = r_N )</td>
<td>( r_M = r_N ) asympt</td>
</tr>
<tr>
<td>Imitation</td>
<td>turned on; ( \frac{M}{M} &gt; 0 )</td>
<td>turned off; ( \frac{M}{M} = 0 )</td>
<td>turned on; ( \frac{M}{M} &gt; 0 )</td>
</tr>
<tr>
<td>Innovation</td>
<td>turned off; ( \frac{N}{N} = 0 )</td>
<td>turned on; ( \frac{N}{N} &gt; 0 )</td>
<td>turned on; ( \frac{N}{N} &gt; 0 )</td>
</tr>
</tbody>
</table>
1.4.2 The evolution of $\beta$

$$\beta = (a - b)$$

Figure 1.5 Regime 1 Dynamics
β, α

\[ \beta = (a - b) \]

Figure 1.6 Regime 2 Dynamics

β, α

\[ \alpha = \beta = (a - b - M) \]

Figure 1.7 Regime 3 Dynamics
In order to understand the steady state results, a thorough explanation of the evolution of $\beta$ is needed because this is the key determinant of whether the economy in country B ends up in regime 1, 2, or 3. Figures 1.5 -1.7 show how the two efficiency parameters $\alpha$ and $\beta$ change as the number of imitated goods increases. As the figures show, $\alpha$ is constant and does not change, but $\beta$ increases. Figure 1 shows the trajectory of $\beta$ for a country that begins as a product imitator and reaches its BGP and continues to imitate. As can be seen from the figure, the productivity\textsuperscript{28} of R&D workers, who imitate country A’s products, is always greater than the productivity of R&D workers, who invent new products. This means that the rate of return to innovation is less than the rate of return to imitation so firms only invest in imitation.

How a country can start out in regime 1 and then end up in regime 2 is illustrated in figure 1.6. In the beginning, the rate of return of imitation is greater than the rate of return to innovation, so firms invest in reverse engineering and imitating goods. As the knowledge stock increases, the productivity of R&D workers, who invent new products, increases as well. As the knowledge stock of imitated goods continues to increase, workers become more efficient at innovating\textsuperscript{29} than imitating, so firms stop imitating and will only innovate in the steady state once $\alpha + \frac{\delta \eta w}{\lambda E} = \beta$. Then all firms invest in R&D aimed at innovating only (regime 2) because the rate of return to both types of R&D are equal. The perfect foresight Nash equilibrium guarantees that once $M^*$ is reached, no entrepreneur is willing to invest in imitation. After $M^*$, the rate of return to imitation is less than the rate of return to innovation, so firms are not willing to invest in this type of R&D anymore.

It is also possible for a country to start out as an imitator, but end up as a country that

\textsuperscript{28}Throughout this dissertation, it is assumed that efficiency affects and determines productivity, so the terms efficiency and productivity are used interchangeably.

\textsuperscript{29}The workers have learned how to innovate and $\beta > \alpha$ in finite time.
imitates and innovates. Figure 1.7 shows how a country makes the transition from specializing in imitation only to equally investing in innovation based R&D and imitation based R&D. In this case, at first, it is more profitable for firms to imitate country A’s products because researchers are more efficient at imitating than innovating. As the knowledge stock increases, and researchers benefit from the learning to innovate process, they become more effective at inventing new products. Asymptotically, $\alpha = \beta$. Along the BGP, there will be both imitation and innovation. Entrepreneurs are willing to invest in both types of research because the rate of return to imitation is equal to the rate of return to innovation, and the possibility does not exist for the rate of return to innovation to be greater than the rate of return to imitation.

### 1.5 General Equilibrium Results

General Equilibrium is defined by equations (1.8), (1.18) and the labor market clearing condition which states that the total amount of labor that is available in a country is equal to the amount of workers that work in each sector of the economy i.e. all of the labor force that is dedicated to manufacturing intermediate goods, plus all of the R&D researchers equal the total labor force. Mathematically, this means that

$$L = L_X + L_M + L_N = \frac{LE}{P_X} + \frac{M}{\alpha N_B} + \frac{N}{\beta N_B} \tag{1.24}$$

The general equilibrium results indicate that there are three possible growth regimes that the economy can converge to: the economy in country B can evolve over time and end up in a steady state with firms that specialize in imitating; the economy in country B can evolve over time and end up in a steady state with firms that specialize in innovating; or the the
economy in country B can evolve over time and end up in a steady state with firms that specialize in both imitation and innovation. The conditions that lead to each growth regime have already been discussed in detail in the previous section.

### 1.5.1 Steady State Results: Regime 1

When $\alpha > \beta$, the economy is similar to the Grossman and Helpman (1991b) model. Firms specialize in imitating country A’s goods, so all market entrants use their resources to concentrate on research that enables them to become better imitators of these goods. No firm will invest in inventing new goods because it is not profitable for them. A developing country can end up in regime 1 if the learning to innovate effect does not increase the productivity of R&D workers sufficiently enough to make innovation feasible. This occurs if a country is either too far away from the technology frontier of country A, or if the country’s initial efficiency and/or quality of its workforce is quite low and hinders the learning to innovate effect.\(^{30}\) When this situation occurs, solving for the steady state is straightforward because $\dot{N} = 0$, so $N_B = M$ and (1.12) reduces to

$$\frac{N_B}{N_B} = \frac{M}{M}$$

(1.25)

Using the pricing strategy from (1.19), the value of the firm from (1.16), and plugging (1.25) into (1.24) yields

$$\frac{N_B}{N_B} = \alpha L - \frac{LE(\eta - 1)}{\eta \nu N_B}$$

(1.26)

\(^{30}\)This would be the equivalent to having a high $b$ and a low $a$. 

35
A country’s growth rate of the number of imitated goods depends on the efficiency of its workers \((\alpha)\), and the number of workers that are used to make intermediate goods \(X\). A high \(\alpha\) and more workers dedicated to conducting R&D translates into a higher growth rate, while a low \(\alpha\) and less workers dedicated to R&D translate into a lower growth rate of imitated products. Following the method of G-H, in order to simplify the analysis, I define the rate at which new product varieties are being introduced into the economy as \(\frac{N_B}{N_B} \equiv g_M\), and I define the inverse of the economy’s aggregate equity value as \(V \equiv \frac{1}{n_N}\). Now, I can rewrite (1.26) as

\[
g_M = \alpha L - \frac{LE(\eta-1)V}{\eta} \tag{1.27}
\]

Using the definitions of \(V\) and \(g_M\), it is apparent that

\[
\frac{\dot{V}}{V} = -\frac{\dot{V}}{V} - g_M \tag{1.28}
\]

Plugging the definitions of \(g_M\) and \(V\) into (1.18) yield

\[
\frac{\dot{V}}{V} = \frac{LEV}{\eta} - \rho - g_M \tag{1.29}
\]

With these substitutions, the general equilibrium of the economy is determined by the differential equation (1.29) and the condition (1.27). Figure 1.8 illustrates the equilibrium dynamics of the economy.
The LL curve represents the resource constraint of the economy. Firms allocate labor either exclusively to manufacturing, exclusively to R\&D, or to some efficient combination of both activities. The possible combinations of this division of labor are located only on the LL curve. The \( VV \) line represents combinations of \( V \) and \( g_M \) that maintain the relationship that the growth rate of imitated product varieties is exactly equal to the rate of decline in the value of new firms i.e \( \dot{V} = 0 \) in (1.28). A higher growth rate of imitated varieties implies that more resources are devoted to R\&D and less resources are devoted to manufacturing.

A stable equilibrium is achieved only at point E. At this point, the number of imitated varieties grows at the constant rate \( g_M \), labor is divided between manufacturing and R\&D at a constant ratio, and the aggregate value of firms does not change. The economy must jump to this steady state, which means that there are no transitional dynamics. The directional arrows show how \( V \) changes as the division of labor changes. The changes in \( V \), that must
occur if the economy is not at point E, are instrumental in showing why the economy jumps directly to its steady state. To the left of E (along the LL line), wages and prices decrease as output increases, the value of the firm decreases at an increasing rate and $V$ increases. To the right of E (along the LL line), wages and prices increase as output decreases, the value of the firm decreases at a decreasing rate and $V$ decreases. Equation (1.29) shows that this occurs because of differences in the growth rate of imitated varieties and the decline in firm value. If $g_M$ is bigger than the decline in firm value, then $V$ decreases. If $g_M$ is less than the decline in firm value, then $V$ increases. These results imply that points outside of E either lead to a $V$ that goes to infinity, or a $V = 0$. Both results cannot be achieved because they violate the general equilibrium conditions. This means that the economy jumps to its stable equilibrium point E. Solving for $V$ using (1.28) yields

$$g_M = \frac{\alpha L}{\eta} - \frac{(\eta - 1)\rho}{\eta} \tag{1.30}$$

The number of imitated varieties grows at this constant rate along the BGP. Continued imitation is possible because the cost of market entry decreases with the number of firms (the available knowledge stock), offsetting the decrease in profits that occurs as the number of firms increases. A country’s steady state growth rate depends on the productivity of its R&D workers, the subjective discount rate, the size of its labor force, and the elasticity of product substitution. Having a more productive workforce increases the growth rate of imitated goods while having a less productive workforce decreases the growth rate. A higher subjective discount rate leads to a lower growth rate of imitated goods because consumers value present consumption more than future consumption. A lower subjective discount rate leads to a higher growth rate as consumers are more willing to wait to consume goods. A lower subjective discount rate means that consumers save more, the cost of capital is lower,
and more entrepreneurs are willing to conduct R&D and enter the market with imitated products. A larger labor force increases the growth rate since more resources can be devoted to manufacturing intermediate goods and conducting research. A smaller labor force decreases the growth rate. A higher value of the elasticity of product substitution leads to a lower growth rate as consumers value product variety less, so the market power of market entrants is smaller; thereby, leading to less entry by entrepreneurs. A lower value of the elasticity of product substitution has the opposite effect on the growth rate.

A more precise explanation of what is growing in this model is needed in order to be able to discuss the dynamics of economic growth. In keeping with the Grossman and Helpman (1991) model, I have interpreted the consumption index using Ethier’s definition. This means that consumers in country B consume a single homogeneous good in quantity $C$. This final good is produced using differentiated intermediate inputs or producer services. In other words, variety expansion occurs in the number of intermediate goods that are available. These intermediate goods are then used to produce one final good $C$. Using this definition, it becomes apparent that economic growth occurs with the growth rate of $C$. In order to calculate the growth rate of $C$, I use

$$C = \left[ \int_{0}^{N_B} C_i e^{(\eta-1)/\eta} d_i \right]^{\eta/(\eta-1)}$$  \hspace{1cm} (1.31)

I then substitute the following into (1.31)

$$\frac{X_i}{L} = C_i = \frac{L_{p_i}}{L}$$

Taking the derivative of the log of (1.31) yields
\[ g_c = \frac{\eta N_B}{(\eta - 1) N_B} \quad (1.32) \]

The growth rate of C depends on the growth rate of intermediate goods. In regime 1, the growth rate of C is (1.30). This means that the growth rate of income per capita depends on the rate of product creation by entrants. The assumption of a symmetric equilibrium and the Dixit-Stiglitz production function makes it easy to calculate total factor productivity (TFP) \(^{31}\) for the economy which is

\[ TFP = N_B^{\frac{1}{(\eta - 1)}} \]

and the growth rate of TFP is

\[ g_{TFP} = \frac{1}{(\eta - 1)} \frac{N_B}{N_B} \quad (1.33) \]

The level of TFP increases with the number of product varieties, and the growth rate of TFP increases with the rate of product creation by entrants which is consistent with the empirical data. \(^{32}\)

### 1.5.2 Steady State Results: Regime 2

When \( \alpha + \frac{\delta \eta w}{w L} = \beta \), firms specialize in innovating, so all market entrants use their resources to concentrate on research that enables them to become better innovators in the steady state. No firm will invest in imitating country A’s goods because it is not profitable for them. The

---

\(^{31}\) Final output per unit of primary input which is equal to \( \frac{C}{X} \)

\(^{32}\) This will be discussed in more detail in Section 1.6.
possibility that firms only innovate in the steady state is an improvement on the traditional G-H model which completely excludes product innovation by developing countries. The transition from imitation to innovation is not mechanical like the Currie model and occurs due to the increase in $\beta$. This occurs if the initial quality of a country’s initial workforce is high enough so that the ability of R&D workers to innovate is augmented sufficiently enough by the learning to innovate effect to make innovation more profitable than imitation.\(^{33}\) When countries specialize in innovation only, solving for the steady state is straightforward because $M = 0$, and (1.12) reduces to

$$\frac{N_B}{N_B} = \frac{N}{N_B}$$

(1.34)

Using the pricing strategy from (1.19), the value of the firm from (1.17), and plugging (1.34) into (1.24) yields

$$\frac{N_B}{N_B} = \beta L - \frac{LE(\eta - 1)}{\eta v N_B}$$

(1.35)

A country’s growth rate of the number of innovated goods depends on the efficiency of its workers ($\beta$), and the number of workers that are used to make intermediate goods $X$. A high $\beta$ and more workers dedicated to conducting R&D translates into a higher growth rate, while a low $\beta$ and less workers dedicated to R&D translate into a lower growth rate of innovated products. The method of solving for the steady state value of (1.35) in regime 2 is exactly the same as the method I used in regime 1. I define the rate at which new product varieties are being introduced into the economy as $\frac{N_B}{N_B} \equiv g_N$, and I define the inverse of the economy’s aggregate equity value as $V \equiv \frac{1}{vN_B}$. I rewrite (1.35) as

\(^{33}\)This would be the equivalent to having a high $a$ and a low/medium $b$.  

41
\[ g_N = \beta L - \frac{LE(\eta-1)V}{\eta} \]  

(1.36)

Plugging the definitions of \( g_N \) and \( V \) into (1.18) yield

\[ \frac{\dot{V}}{V} = \frac{LEV}{\eta} - \rho - g_N \]  

(1.37)

With these substitutions, the general equilibrium of the economy is determined by the differential equation (1.37) and the condition (1.36). Figure 1.9 illustrates the equilibrium dynamics of the economy. Based on the same logic that was used in regime 1, the economy in regime 2 jumps to the temporary equilibrium \( E' \). At this point, the number of imitated varieties grows at the constant rate \( g_M \), labor is divided between manufacturing and R&D at a constant ratio, and the aggregate value of firms does not change.

Figure 1.9 General Equilibrium Dynamics
Over time, the number of imitated varieties grows at this constant rate and eventually, as $M$ increases and reaches $M^*$, $\beta$ increases as well until $\beta > \alpha$ in finite time. At this point, new firms enter the market as innovators only because they recognize that if they enter as an imitator, they will earn less of a return to their investment. After $M^*$, resources are shifted from imitation to innovation. At this point, the LL curve moves out, and the economy jumps to its new, stable equilibrium $E''$. Now, firms only innovate, so in the steady state, the number of varieties grows at the constant rate $g_N$. Solving for $V$ using (1.37) yields

$$g_N = \frac{\beta L}{\eta} - \frac{(\eta-1)\rho}{\eta}$$

(1.38)

The number of product varieties grows at this constant rate along the BGP. Continued innovation is possible because the cost of market entry decreases with the number of firms (the available knowledge stock), offsetting the decrease in profits that occurs as the number of firms increases. The steady state growth rate depends on the productivity of R&D workers, the discount rate, the size of the labor force, and the elasticity of product substitution.\textsuperscript{34} Once again, the growth rate of income per capita and the growth rate of TFP depend on the rate of product creation by entrants which is $g_N$ in regime 2. Since $\beta > \alpha$ in regime 2, this means that the growth rate of income and the growth rate of TFP will be higher in regime 2 than in regime 1. The reason for this is the fact that as R&D workers become more efficient at inventing, more entrepreneurs are motivated to enter new markets as innovators at a faster rate as entry costs decrease more in regime 2 than 1. The benefit of being able to transition from imitation to innovation because of the learning to innovate effect is the fact that it becomes possible to have a higher growth rate of output and TFP without market intervention.

In the traditional G-H variety expansion model, this result is only possible with a subsidy.

\textsuperscript{34} A precise explanation of how the productivity of R&D workers, the discount rate, the size of the labor force, and the elasticity of product substitution affect the growth rate is given in Section 1.5
1.5.3 Steady State Results: Regime 3

When $\alpha = \beta$ asymptotically, firms specialize in innovating and imitating, so market entrants use their resources to concentrate on research that enables them to become better innovators and imitators in the steady state. The possibility that firms can innovate and imitate in the steady state is an improvement on the traditional G-H model which completely excludes this outcome. Once again, the transition from imitating to conducting both types of research is not mechanical like the Currie model and occurs due to the increase in $\beta$. When this situation occurs, solving for the steady state is straightforward because $\beta = \alpha$ asymptotically, so (1.12) reduces to

\[
\frac{\dot{N}_B}{N_B} = \frac{M}{N_B} + \frac{\dot{N}}{N_B} \quad (1.39)
\]

Once again, Figure 1.8 illustrates the equilibrium dynamics of the economy. The economy jumps to its equilibrium point E. At first, only the number of imitated varieties grows at this constant rate. As $M$ increases, and $\beta$ increases, so that $\beta = \alpha$, asymptotically, firms begin to invest in inventing new products. In the steady state, firms allocate resources to both R&D focused on imitating goods and R&D focused on inventing goods. The growth rates of imitating and innovating goods adjust until the growth rate of total product varieties is constant at

\[
\frac{\dot{N}_B}{N_B} = \frac{M/M}{(N+M)/M} + \frac{\dot{N}/N}{(N+M)/N} \quad (1.40)
\]

Using the same logic to solve for the steady state that was used in regimes 1 and 2, it follows that
\[ g_{NB} = \frac{\alpha L}{\eta} - \frac{(\eta - 1)\rho}{\eta} \]  

(1.41)

The number of product varieties grows at this constant rate along the BGP. Continued growth is possible because the cost of market entry decreases with the number of firms (the available knowledge stock), offsetting the decrease in profits that occurs as the number of firms increases. The steady state growth rate depends on the productivity of R&D workers, the discount rate, the size of the labor force, and the elasticity of product substitution.\(^{35}\) Once again, the growth rate of income per capita and the growth rate of TFP depend on the rate of product creation by entrants which is \(g_{NB}\) in regime 1. Since \(\beta = \alpha\) in regime 3, this means that the growth rate of income and the growth rate of TFP will be the same as in regime 1. The reason for this is the fact that R&D workers are just as efficient at imitating as they are at inventing, and the rate of product entry remains the same because the decrease in the cost of entry is the same in both regimes.

### 1.6 Empirical Implications

This section discusses the testable implications of my research. My model predicts that the determining factor in being able to transition from imitation to innovation is labor efficiency. My research shows that improvements in efficiency are more important than improvements in technology if a developing country wishes to transition from imitation to innovation because changes in the efficiency of labor affect overall labor productivity more than changes in technology. My research also shows that technology diffusion increases the chances of transitioning from imitation to innovation because it increases the productivity of R&D

\(^{35}\) A precise explanation of how the productivity of R&D workers, the discount rate, the size of the labor force, and the elasticity of product substitution affect the growth rate is given in Section 1.5.
workers, who innovate. Increases in productivity lower the cost of innovation and provide entrepreneurs with the incentive to create new products. I also conclude that domestic R&D efforts are an essential part of both the technology diffusion and learning to innovate process.

My model also predicts that if two developing countries (country 1 and country 2) begin with the same initial conditions and assign an identical number of workers to R&D, and country 1 innovates in the steady state, while country 2 does not, then it must be because of differences in the efficiency of labor in each country. If this situation arises then it must be that workers in country 1 are more efficient, healthier and better educated than workers in country 2. In other words, the healthier, better educated workforce in country 1 benefited more from the learning to innovate effect than workers in country 2. My research finds that increases in the efficiency of labor in the R&D lab is what leads to successful product innovation by firms.

Another prediction my model makes is that if two developing countries (country 1 and country 2) begin with the same initial conditions and allocate an equal amount of workers to R&D and both countries innovate in the steady state, but country 1 has a higher steady state growth rate than country 2, then it must also be because of differences in the efficiency of labor in each country. If this situation arises then it must be that R&D workers in country 1 are more efficient, healthier and better educated than workers in country 2. Once again, the healthier, better educated workforce in country 1 benefited more from the learning to innovate effect than workers in country 2.

It is possible to use firm and plant level panel data to test these predicted results at the

\[36\text{The initial conditions are having the same values for the elasticity of substitution, number of firms, and the subjective discount rate.}\]
micro level. Because my model is built on micro fundamentals, it should be the case that whatever trends we see empirically at the micro level should also be seen at the aggregate level. In order to substantiate my results, the empirical evidence should show that worker’s skill and efficiency are important for transitioning from imitation to innovation. The data should also show that domestic R&D augments the diffusion of technology, and technology diffusion increases the efficiency of R&D workers who innovate. Jefferson and Zhong (2002) investigate the performance of R&D efforts in 1,826 firms in ten Asian cities and find that the level of education obtained by management and “the purchase of outside technology, including the purchase of foreign licenses, enhances the effectiveness of R&D (13)” aimed at inventing new products or processes and increases productivity. Deolalikar and Evenson (1989) analyze panel data on Indian firms and conclude that international inventive activity has a strong, positive causal effect on domestic inventive activity within India. They also find that technology that is purchased from abroad and in house R&D are complements to each other; further suggesting that there is a learning to innovate effect.

Chudnovsky et al. (2006) study panel data on 718 firms in Argentina and find that R&D efforts and technology diffusion increase the probability that a firm can invent a new product or process. The authors conclude that firms that employ more skilled workers are more likely to invest in R&D that is aimed at inventing new products and processes. Sanguinetti (2005) also uses panel data from Argentina to research what factors determine the innovation expenditures of firms. He finds that the average industry skill level of the labor force has a positive, significant effect on innovation activities. Braga and Willmore (1991) use data

37 Jefferson and Zhong (2002) test this assumption using firm level date from ten Asian cities. They assume that the results they obtain at the firm level should also be observed at the city (aggregate) level.
38 This is the learning to innovate effect.
39 Both authors assert that “the flow of international technology stimulates Indian invention (692).”
collected from a cross section of 4342 firms in Brazil to investigate what factors influence a firm’s decision to either import technology from abroad or innovate. The authors conclude that firms that import technology have a higher probability of innovating and developing new products.\(^{40}\)

My model also predicts that an increase in the level (growth rate) of product variety has a positive effect on the level (growth rate) of output and TFP. In order to substantiate these results, the empirical research should provide evidence that the level (growth rate) of product variety and the level (growth rate) of TFP are positively correlated. Addison (2003) investigates this correlation using data for 29 (13 developed and 16 developing) countries. He concludes\(^{42}\) that there is a strong positive correlation between the level of product variety and the level of both output and TFP. Addison also finds that the growth rate of product variety and the growth rate of TFP are positively correlated.

### 1.7 Conclusion

The model presented in this dissertation incorporates the idea that as a firm in a less developed country spends money on R&D aimed at imitating technology from abroad, a knowledge spill-over effect makes workers more productive at innovating. As the cost of innovation decreases, firms can transition from imitating to inventing their own goods. The most important contribution my research makes to the literature is that it presents a variety expansion model that has an endogenous process for learning to innovate that is dynamic and not mechanical and is consistent with the empirical evidence. The model explains how a

\(^{40}\)What I have labeled imitation of a developed country’s products.

\(^{41}\)What I have called learning to innovate.

\(^{42}\)One can argue that his proxy for product variety (export variety) is flawed, but it has been proven to be the only reliable proxy that is available at this time.
developing country can transition from imitating products to inventing new products; why some countries can make this transition, while other countries can not. My research also suggests that there are two important benefits for countries if they can make the transition from imitating to innovating.

The traditional Grossman and Helpman model of technology diffusion maintains that a less developed country will always imitate and never opt to innovate. When I incorporate learning to innovate in a traditional variety expansion model, I find that this result does not hold. The process of learning to innovate makes it possible for less developed countries to transition from imitating to innovating. In my model, the transition from imitation to innovation occurs because of a learning process that increases productivity and lowers the cost of innovation. It is not a mechanical switch like the one in the Currie model. In their paper, the transition from imitation to innovation occurs only after the authors assign different values to certain parameters. The Glass model of transitioning from imitation to innovation is also mechanical. She assumes that government intervention influences the investment decisions of firms, and this is what drives the decision to innovate or imitate. Connolly and Valderrama do incorporate a process of learning to learn in their model; however, the authors do not explicitly address the question of why some countries learn how to innovate, and they solve their model numerically. I have developed a coherent model of learning to innovate that is not mechanical and has closed-form solutions.

With the learning to innovate process, there are three possible steady state results. A country can either become a perpetual innovator. It can become a perpetual imitator, or it can converge to a steady state where it does a combination of both innovation and imitation. Productivity differences between researchers in different countries is the main determinant of whether a country transitions from imitating and reverse engineering products to invent-
ing products that are new to the world. The results presented in this chapter of my dissertation show how important technology diffusion is to developing countries that want to learn how to innovate their own products. By assuming that the productivity of labor depends on both the level of technology that is available within a country and how efficient workers are, it becomes apparent that labor efficiency and tacit knowledge are very important for technology diffusion, product imitation, and possible subsequent innovation by firms. Labor efficiency is what determines whether a developing country can transition from reverse engineering and imitating a more developed country’s products to inventing its own products. My research predicts that developing countries that have a healthier and more educated workforce can benefit the most from reverse engineering and learning to learn and are more likely to transition from imitating to innovating. On the other hand, countries that have workers, who lack the skills necessary to learn how to innovate from reverse engineering more technologically advanced products from abroad, will likely opt to continue to imitate products instead of inventing new products. If a developed country manages to use the knowledge it accumulates through technology diffusion to learn how to invent its own products, it will be rewarded for its efforts by having a higher level (growth rate) of both output and TFP.
Chapter 2

Government Intervention in the Economy

2.1 Introduction

In chapter 1, I modify a traditional variety expansion model to include a learning to innovate effect that made it possible for developing countries to transition from just imitating and reverse engineering an advanced country’s products to inventing its own products. I investigate the effects of the learning to innovate process on endogenous growth and TFP and concluded that a country will grow faster and have a higher growth rate of TFP if it successfully reaches a steady state where it innovates only. The results from chapter 1 are interesting because they explain how a developing country can transition from imitating a more advanced country’s products to inventing new products as well as explaining why and how some developing countries can successfully make this transition, while other countries can not. Most of the endogenous growth literature has not addressed this issue with respect to technology diffusion and learning to innovate.

The set-up of my model also contributes to the literature on endogenous growth because it allows for an analysis of government intervention in the economy that extends beyond the scope of most of the research that has been conducted on technology diffusion at the macro
level. Not only is my model useful for investigating the effects of subsidies to R&D and manufacturing on growth and TFP, but it is also useful for researching how governments can promote innovation and growth by subsidies to education as well.

The focus of this chapter is two-fold. The first objective is to look at how government intervention in the economy can affect whether a developing country transitions from imitating to innovating new products. Section 2.2 analyzes how the government can intervene in the economy to raise the efficiency level of workers and the effect this will have on the decisions of firms to either imitate or innovate in the steady state. The second objective of this chapter is to assess the Pareto optimality of the steady state results of the decentralized economy that were obtained in chapter 1. Section 2.3 compares the free market equilibrium results to Pareto optimal equilibrium results. Section 2.4 concludes.

2.2 Intervention in the Education (Health) Sector of the Economy

As already investigated in great detail in Chapter 1, entrepreneurs decide to enter new markets as either imitators or innovators. The entry technology is characterized by two different equations based on whether a good is imitated or invented:

\[
\dot{M} = \alpha N_B L_M, \quad \alpha > 0 \tag{2.1}
\]

\[
\dot{N} = \beta (M) N_B L_N, \quad \beta (M) > 0 \tag{2.2}
\]

The parameter \( \beta \) is a function of \( M \) and evolves as follows:

\[
\beta (M) = a - be^{-M} \tag{2.3}
\]
As explained in Chapter 1, the evolution of both $\beta$ and $\alpha$ determine whether a developing country continues to imitate only, does both imitation and innovation, or transitions to innovating only. One of the main conclusions reached in Chapter 1 was that the learning to innovate process had the biggest effect on R&D workers in countries that had a better educated and healthier workforce. One of the main assumptions that was made in the chapter was that the economy started out with an initial average level of worker’s health and education that did not change. In order to investigate the effect of government intervention in the economy, that assumption will be relaxed in this section and the next. Now, it is assumed that the efficiency parameters of labor ($\alpha$) and ($\beta$) both depend on the mean education level of the workforce ($\tilde{S}$) and the average health of the workforce ($\bar{H}$) such that

$$\alpha(\tilde{S}, \bar{H})$$

$$\beta(M, \tilde{S}, \bar{H})$$

and once the economy is in its steady state, the government decides to intervene in the economy with a lump-sum investment that increases the average education and health level of the workforce. To keep the analysis simple, it is assumed that the effects of the investment are direct and immediate, so there are no diffusion lags. It is also assumed that $\frac{\partial \beta}{\partial \bar{H}} > \frac{\partial \alpha}{\partial \bar{H}}$ and $\frac{\partial \beta}{\partial \bar{E}} > \frac{\partial \alpha}{\partial \bar{E}}$. The effect of this government intervention in the economy can have a variety of consequences. The focus of this section is to analyze how this government intervention affects the investment decisions of firms; thereby, affecting whether a developing country continues to be a imitator country or transitions to innovating.
2.2.1 Regime 1 Results with Government Intervention

A developing country ends up in Regime 1 if it continues to be more profitable for firms to imitate instead of innovating taking into account the learning to innovate process. Once the economy is in its steady state and firms specialize in innovating only, government intervention that improves the average education and health level of workers will affect the steady state growth rate and TFP and might affect the investment decision of firms. Table 2.1 lists the various scenarios that can occur after there are improvements in worker’s health and education. The tildas represent the new values after government intervention. What actually happens depends on whether the changes in education and health are sufficient enough to make workers either more efficient at innovating than imitating, or if the impact of government intervention is insufficient to initiate such a change.
Table 2.1 Government Intervention in Regime 1

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>$\tilde{\alpha} &gt; \tilde{\beta}$</td>
<td>$\tilde{\alpha} + \frac{\delta \eta^w}{\eta} = \tilde{\beta}$</td>
<td>$\tilde{\alpha} = \tilde{\beta}$ asympt</td>
</tr>
<tr>
<td>Imitation</td>
<td>turned on; $\frac{M}{M} &gt; 0$</td>
<td>turned off; $\frac{M}{M} = 0$</td>
<td>turned on; $\frac{M}{M} &gt; 0$</td>
</tr>
<tr>
<td>Innovation</td>
<td>turned off; $\frac{N}{N} = 0$</td>
<td>turned on; $\frac{N}{N} &gt; 0$</td>
<td>turned on; $\frac{N}{N} &gt; 0$</td>
</tr>
<tr>
<td>SS Growth Rate</td>
<td>$g_M = \frac{\alpha L}{\eta} - \frac{(\eta-1)\rho}{\eta}$</td>
<td>$g_N = \frac{\tilde{\beta} L}{\eta} - \frac{(\eta-1)\rho}{\eta}$</td>
<td>$g_{Nb} = \frac{\alpha L}{\eta} - \frac{(\eta-1)\rho}{\eta}$</td>
</tr>
</tbody>
</table>

If government intervention raises the efficiency of labor in both R&D sectors of the economy, but the increase is not enough to make R&D workers in the innovation sector of the economy more efficient at innovating than imitating, then the economy will continue to imitate at a constant rate in the new general equilibrium after government intervention. Government intervention has succeeded in increasing the growth rate, but the country has still not managed to learn how to innovate. A possible explanation as to why such a situation could occur might be that the education and health levels of workers are so low, that even with government intervention, it still did not provide the fundamentals in the economy that are necessary for successful innovation. Figure 2.1 illustrates the equilibrium dynamics of scenario 1.
Initially, the economy has reached its steady state \((E)\), and the growth rate of imitated products is constant. The government intervenes in the economy; thereby increasing the efficiency of workers in both R&D sectors of the economy. Workers remain more efficient at imitating, so at the new steady state \((E')\) firms imitate only, and new imitated product varieties grow at the constant rate \(g_M = \frac{\alpha L}{\eta} - \frac{(\eta-1)\rho}{\eta}\). This rate is higher than the growth rate that occurs without government intervention \(g_M = \frac{\alpha L}{\eta} - \frac{(\eta-1)\rho}{\eta}\) because \(\bar{\alpha} > \alpha\). Thus, government intervention increases the growth rate of output per capita and TFP, but it does not transition the economy from imitating to innovating.

If government intervention raises the efficiency of labor in both R&D sectors of the economy, and the increase is enough to make R&D workers in the innovation sector of the economy more efficient at innovating than imitating, then the economy will stop imitating and start innovating at a constant rate in the new general equilibrium after government
intervention. Government intervention has succeeded in increasing the growth rate, and
the country has managed to learn how to innovate. A possible explanation as to why such
a situation could occur might be that the education and health levels of workers are high
enough, so that with government intervention, it provides the fundamentals in the economy
that are necessary for successful innovation. Figure 2.2 illustrates the equilibrium dynamics
of scenario 2.

Initially, the economy has reached its steady state \((E)\), and the growth rate of imitated prod-
ucts is constant. The government intervenes in the economy; thereby increasing the effi-
ciency of workers in both R&D sectors of the economy. Workers become more efficient at
innovating, so at the new steady state \((E''\) firms innovate only, and new innovated product
varieties grow at the constant rate \(g_N = \frac{\beta L}{\eta} - \frac{(\eta - 1)\rho}{\eta}\). This rate is higher than the growth
rate that occurs without government intervention \(g_M = \frac{\alpha L}{\eta} - \frac{(\eta - 1)\rho}{\eta}\) because \(\bar{\beta} > \alpha\). Thus,
government intervention increases the growth rate of output per capita and TFP, and it trans-
itions the economy from imitating to innovating.

If government intervention raises the efficiency of labor in both R&D sectors of the econ-
omy, and the increase is enough to make R&D workers equally efficient at innovation and imitation asymptotically, then the economy will imitate and innovate at a constant rate in the new general equilibrium after government intervention. Government intervention has succeeded in increasing the growth rate, and the country has managed to learn how to innovate, but the country does not specialize in innovating products because R&D workers are equally efficient at both types of product development. A possible explanation as to why such a situation could occur might be that the education and health levels of workers are raised just enough with government intervention to make innovation just as profitable, but not more profitable than imitation. Figure 2.1 illustrates the equilibrium dynamics of scenario 3 as well.

Initially, the economy has reached its steady state (\(E\)), and the growth rate of imitated products is constant. The government intervenes in the economy; thereby increasing the ef-

ciency of workers in both R&D sectors of the economy. Workers become equally efficient at innovating and imitating asymptotically, so at the new steady state (\(E''\)) firms innovate and imitate, and the growth rate of imitated products and the growth rate of innovated prod-

ucts adjust enough, so that the total amount of product varieties grows at the constant rate

\[
g_{N_B} = \frac{\tilde{\alpha}L}{\eta} - \frac{(\eta-1)\rho}{\eta}\). \text{ This rate is higher than the growth rate that occurs without government intervention } g_{N_B} = \frac{\alpha L}{\eta} - \frac{(\eta-1)\rho}{\eta} \text{ because } \tilde{\alpha} > \alpha. \text{ Thus, government intervention increases the growth rate of output per capita and TFP, and it transitions the economy from just imitating in the steady state to dedicating resources to both activities: imitating and innovating.}
2.2.2 Regime 2 and 3 Results with Government Intervention

The results of government intervention on the steady state of the economy are more straightforward for regimes 2 and 3. Since $\frac{\partial \beta}{\partial H} > \frac{\partial \alpha}{\partial H}$ and $\frac{\partial \beta}{\partial E} > \frac{\partial \alpha}{\partial E}$, then any intervention by the government to increase the average education and health level of the labor force, will lead to a new steady state where firms continue to specialize in innovating only. Figure 2.3 illustrates the equilibrium dynamics for regime 2. In regime 2, firms specialize in innovating only in the steady state, and with government intervention, they continue to invest in innovating only. As workers become more efficient, the growth rate of product varieties increases, and the economy moves from the old steady state $(E)$ to the new steady state.

New innovated product varieties grow at the constant rate $g_N = \frac{\beta L}{\eta} - \frac{(\eta-1)\rho}{\eta}$. This rate is higher than the growth rate that occurs without government intervention $g_{NB} = \frac{\alpha L}{\eta} - \frac{(\eta-1)\rho}{\eta}$ because $\tilde{\beta} > \beta$. TFP also increases with government intervention.

Figure 2.4 illustrates the equilibrium dynamics for regime 3. In regime 3 firms invest in both innovation and imitation. With government intervention, firms will only invest in innovation because it becomes more profitable; thereby, intervention causes the economy to switch from conducting two types of R&D to innovating only. At the new steady state, new innovated product varieties grow at the constant growth rate $g_N = \frac{\tilde{\beta} L}{\eta} - \frac{(\eta-1)\rho}{\eta}$. This rate is higher than the growth rate that occurs without government intervention $g_{NB} = \frac{\alpha L}{\eta} - \frac{(\eta-1)\rho}{\eta}$ because $\tilde{\beta} > \alpha$. TFP also increases with government intervention.
Figure 2.3 General Equilibrium Dynamics

Figure 2.4 General Equilibrium Dynamics
2.3 Pareto Optimality and Government Intervention

The decentralized economy is concerned with calculating the optimal growth rate of output per capita that maximizes the representative household’s utility

\[ U = \int_0^\infty e^{-(\rho)t} \log C_i dt, \quad \rho > 0 \]  

(2.7)

with the consumption index \( C \):

\[ C = \left[ \int_0^{N_B} C_i^{(\eta-1)/\eta} dt \right]^{\eta/(\eta-1)}, \quad \eta > 1 \]  

(2.8)

subject to the flow budget constraint

\[ \dot{A} = Ar + w - E \]

In order to investigate whether the results of chapter 1 are Pareto optimal, I compare the following growth rates of output per capita for regimes 1,2, and 3 respectively:

\[ g_{NB} = g_M = \frac{\alpha L}{\eta} - \frac{(\eta-1)\rho}{\eta} \]  

(2.9)

\[ g_{NB} = g_N = \frac{\beta L}{\eta} - \frac{(\eta-1)\rho}{\eta} \]  

(2.10)

\[ g_{NB} = \alpha L - \frac{(\eta-1)\rho}{\eta} \]  

(2.11)

with the optimal steady state results that are obtained under a centralized (hypothetical social planner’s problem) economy. In order to solve the social planner’s problem, I use the method developed by G-H and re-define the consumption index

\[ C = \left[ \int_0^{N_B} X_i^{(\eta-1)/\eta} dt \right]^{\eta/(\eta-1)}, \quad \eta > 1 \]  

(2.12)

With the symmetric equilibrium, \( X_i = \frac{X}{N_B} \); therefore, \( C = N_B^{\eta/(\eta-1)} \frac{X}{N_B} = N_B^{1/(\eta-1)} X \). The social planner’s problem is to maximize the utility of the representative household.
\[ U = \int_{0}^{\infty} e^{-\rho t} \left[ \frac{1}{(\eta - 1)} \log N_B + \log X_t \right] dt, \quad \rho > 0 \]  

subject to the economy’s resource constraint\(^1\)

\[ L = L_X + L_M + L_N = X + \frac{M}{\alpha N_B} + \frac{N}{\beta N_B} \]  

2.4 Pareto Optimal Results vs. the Decentralized Results

2.4.1 Regimes 1 and 3

If the economy ends up in regime 1 or 3 in the long-run, the appropriate resource constraint for the social planner is

\[ L = X + \frac{N_B}{\alpha} \]  

The current valued Hamiltonian\(^2\) for the social planner’s dynamic optimization problem is

\[ H_c = \frac{1}{(\eta - 1)} \log N_B + \log X + \psi \left[ (L - X) \alpha N_B \right] \]  

The FOCs yield

\[ \frac{1}{X} = \psi \alpha N_B \]  

\[ \psi = \psi \rho - \frac{1}{(\eta - 1)N_B} - \psi (L - X) \alpha \]  

\[ \lim_{t \to \infty} \psi t N_B e^{-\rho t} = 0 \]  

\(^1\)Since one unit of labor produces one unit of output, \(L_X = X\).

\(^2\)To simplify the notation, the time subscripts are suppressed throughout the rest of this chapter.
To further help with the analysis, I define the shadow price of the total amount of product varieties that are available in the economy as \( Z \equiv \psi N_B \), so that \( \frac{\dot{Z}}{Z} = \frac{\dot{\psi}}{\psi} + \frac{\dot{N}_B}{N_B} \). This substitution will allow me to solve for the growth rate of product varieties that is Pareto optimal. Using the resource constraint (2.15), to solve for total output \( (X) \), and substituting this result into (2.18) and multiplying both sides by \( N_B \) yields

\[
\dot{\psi} N_B + \dot{N}_B \psi = \psi \rho N_B - \frac{1}{(\eta - 1)}
\]

Using the definition of \( Z \), it is apparent that the flow of the total amount of new product varieties is determined by

\[
\dot{Z} = \rho Z - \frac{1}{(\eta - 1)}
\]  
(2.20)

The benevolent social planner must choose the number of researchers to assign to develop new product varieties so that there is a constant growth rate of innovation that satisfies both (2.20) and the transversality condition

\[
\lim_{t \to \infty} Z_t e^{-\rho t} = 0
\]  
(2.21)

In order to calculate this optimal growth rate, I first need to determine the value of the shadow price of the total number of product varieties that satisfies (2.20) and (2.21). The solution is obtained by setting \( \dot{Z} = 0 \) and solving for \( Z \) to get

\[
Z^* = \frac{1}{(\eta - 1) \rho}
\]  
(2.22)

Solving for output using the resource constraint (2.15) and plugging it into (2.17) yields

\[
\frac{\alpha}{L - g N_B} = Z \alpha
\]  
(2.23)

Substituting for \( Z \) using (2.22) yields

\[\text{all variables that have a * superscript refer to outcomes that are Pareto optimal.}\]
which is the growth rate of product variety that is Pareto optimal for regimes 1 and 3. Having a more productive workforce increases the growth rate while having a less productive workforce decreases the growth rate. A higher subjective discount rate leads to a lower growth rate because consumers value present consumption more than future consumption. A lower subjective discount rate leads to a higher growth rate as consumers are more willing to wait to consume goods. A lower subjective discount rate means that consumers save more, the cost of capital is lower, and more entrepreneurs are willing to conduct R&D and enter the market with products that are new to country B. A larger labor force increases the growth rate since more resources can be devoted to manufacturing intermediate goods and conducting research. A smaller labor force decreases the growth rate. A higher value of the elasticity of product substitution leads to a lower growth rate as consumers value product variety less, so the market power of market entrants is smaller; thereby, leading to less entry by entrepreneurs. A lower value of the elasticity of product substitution has the opposite effect on the growth rate.

By comparing the Pareto optimal growth rate of product variety (2.18) with the decentralized equilibrium growth rates (2.3) and (2.5), it is apparent that the decentralized equilibrium is not Pareto optimal. The growth rate is higher under the social planner. The reason for this is because there are three market distortions that affect the growth rate under the decentralized equilibrium that the social planner can internalize and use to designate resources in the economy efficiently. The first market failure (the inter-temporal-spillover effect) occurs because entrepreneurs are unable to internalize the fact that their R&D efforts have a positive externality; they help future entrepreneurs either imitate or invent new prod-
ucts. The second market failure (the consumer-surplus effect) occurs because entrepreneurs do not internalize the fact that consumers benefit from product variety. The third market failure (the profit-destruction effect) occurs because entrepreneurs are unable to recognize the fact that their R&D efforts and creation of new product varieties erodes the profits of other entrepreneurs, who will eventually enter the market. The consumer-surplus effect and the profit-destruction effect cancel each other out. The failure to internalize the inter-temporal-spillover effect is what leads to a decentralized growth rate that is less than the growth rate that is achieved by the social planner.

Figure 2.5 illustrates the long-run steady state results that are obtained under the decentralized equilibrium and the social planner. In order to aid the analysis, I follow the method of G-H and use a graph that plots the steady state growth rate of product varieties ($g_{NB}$) and the steady state level of aggregate output ($X$). The RC line represents the economy's
resource constraint and has the slope \(-\frac{1}{\alpha}\). The NA line depicts the steady state relationship between the growth rate of product varieties and aggregate output that is determined by the no-arbitrage condition. The no-arbitrage condition is \(r = \frac{\pi_i}{v_i} + \frac{\dot{v}_i}{v_i}\). Using the fact that \(r = \rho\),

\[
\frac{\dot{v}_i}{v_i} = g_{NB}, \quad \frac{\pi_i}{v_i} = \frac{\alpha LE}{\eta w}, \quad X = \frac{LE(\eta - 1)}{\eta w},
\]

and multiplying by \((\eta - 1)\) yields

\[
\frac{\alpha x}{(\eta - 1)} = g_{NB} + \rho \tag{2.25}
\]
as the no-arbitrage condition which is now in terms of the two variables that I want to graph.

The NA line represents the no arbitrage condition for the decentralized equilibrium. The NA’ line represents the relationship between the profit rate (which is expressed in terms of output) and the real interest rate (which is expressed in terms of R&D) that the social planner faces. The intersection of the NA line with the RC line illustrates the combination of nominal expenditure, output and the growth rate of product varieties that is achieved under the decentralized equilibrium. The intersection of the NA’ line with the RC line illustrates the Pareto optimal combination of nominal expenditure, output and the growth rate of product varieties that is achieved by the social planner. The U curve represents the indifference curve that maximizes utility at the given resource constraint. It is tangent to the resource constraint at exactly the point where the resource constraint intersects with the socially efficient growth rate of product varieties.

The main thing to notice from the graph is the fact that the socially efficient growth rate of product variety \((g_{NB}^*)\), nominal expenditure \((E^*)\), and the socially efficient level of output \((X^*)\) are different to the decentralized results. The growth rate is higher, while nominal expenditure and output are lower with the Pareto efficient result. This means that in order for the economy to be efficient, the government will need to intervene. What precisely the government can do to make the decentralized result efficient is discussed in section 2.3. One
thing to note from Figure 2.5 is the fact that government intervention in the economy that successfully increases the growth rate to that of the socially optimum one will lead to both dynamic and static efficiency. This occurs because the increase in the growth rate requires labor, and this decrease in labor increases wages and lowers output sufficiently enough so that with successful government intervention, the decentralized growth rate increases to the social planner’s growth rate, and the decentralized value of output, decreases to the social planner’s level of output. The optimal value of output for both the decentralized result and the social planner is that $X_i = \frac{X}{N}$. This means that there is a symmetric equilibrium such that if aggregate output decreases, each firm produces less of each type of good. The decrease in aggregate output occurs proportionately with the amount of labor that is directed away from manufacturing to R&D. Since aggregate output decreases proportionately with labor, when the government successfully intervenes in the economy to increase the decentralized growth rate to the Pareto optimal growth rate, static efficiency is achieved as well.

When comparing the social planner’s problem to the decentralized equilibrium, I graphed the no arbitrage condition and the resource constraint. With a higher growth rate, the NA curve rotates in a clockwise direction down about its intersection with the horizontal axis. The reason for this is that labor has to be dedicated to either manufacturing or R&D. When labor shifts out of manufacturing to R&D, output decreases proportionately because one unit of labor produces one unit of output. A higher growth rate comes at the expense of aggregate output of manufactured goods.
2.4.2 Regime 2

If the economy ends up in regime 2 in the long-run, the appropriate resource constraint for the social planner is

\[ L = X + \frac{g_{NB}}{\beta} \]  

(2.26)

The current valued Hamiltonian for the social planner’s dynamic optimization problem is

\[ H_c = \frac{1}{\eta - 1} \log N_B + \log X + \psi \left( (L - X) \beta N_B \right) \]  

(2.27)

The FOCs yield

\[ \frac{1}{X} = \psi \beta N_B \]  

(2.28)

\[ \psi = \psi \rho - \frac{1}{(\eta - 1) N_B} - \psi (L - X) \beta \]  

(2.29)

\[ \lim_{t \to \infty} \psi_t N_B e^{-\rho t} = 0 \]  

(2.30)

Using the same method to solve the social planner’s problem that was used in Section 2.2.1, yields that the socially efficient growth rate of product varieties in regime 2 is

\[ g_{NB}^* = L \beta - (\eta - 1) \rho \]  

(2.31)

Once again, comparing the Pareto optimal growth rate of product variety (2.31) with the decentralized equilibrium growth (2.10), confirms that the decentralized equilibrium in regime 2 is not Pareto optimal for the same reasons that were expounded upon in Section 2.2.1. Figure 2.6 illustrates the long-run steady state results that are obtained under the decentralized equilibrium and the social planner. I repeat the same method I used in Section 2.2.1, and I use a graph that plots the steady state growth rate of product varieties \((g_{NB})\) and the steady
state level of aggregate output \((X)\). The RC line represents the economy’s resource constraint and has the slope \(-\frac{1}{\beta}\). The NA line depicts the steady state relationship between the growth rate of product varieties and aggregate output that is determined by the no-arbitrage condition. The no-arbitrage condition is \(r = \frac{\pi}{v_i} + \frac{\dot{v}_i}{v_i}\). Using the fact that \(r = \rho\), \(\frac{\dot{v}_i}{v_i} = g_{Nb}\), \(\frac{\pi}{v_i} = \frac{\beta LE}{\eta w}\), \(X = \frac{LE(\eta - 1)}{\eta w}\), and multiplying by \(\frac{(\eta - 1)}{(\eta - 1)}\) yields

\[
\frac{\beta X}{(\eta - 1)} = g_{Nb} + \rho
\]

as the no-arbitrage condition which is now in terms of the two variables that I want to graph. The NA line represents the no arbitrage condition for the decentralized equilibrium. The NA’ line represents the relationship between the profit rate (which is expressed in terms of output) and the real interest rate (which is expressed in terms of R&D) that the social planner faces. The intersection of the NA line with the RC line illustrates the combination of nominal expenditure, output and the growth rate of product varieties that is achieved under the decentralized equilibrium. The intersection of the NA’ line with the RC line illustrates the Pareto optimal combination of nominal expenditure, output and the growth rate of product varieties that is achieved by the social planner. The U curve represents the indifference curve that maximizes utility at the given resource constraint. It is tangent to the resource constraint at exactly the point where the resource constraint intersects with the socially efficient growth rate of product varieties. The main thing to notice from the graph is the fact that the socially efficient growth rate of product variety \((g_{Nb}^*)\), nominal expenditure \((E^*)\), and the socially efficient level of output \((X^*)\) are different to the decentralized results. The growth rate is higher, while nominal expenditure and output are lower with the Pareto efficient result. This means that in order for the economy to be efficient, the government will need to intervene. What the government can do to make the decentralized result efficient is
discussed in detail in the next section.

2.5 Government Intervention

It is evident that the free-market equilibrium is not Pareto efficient. As already stated, the reason for this is because there are three market distortions that affect the growth rate under the decentralized equilibrium that the social planner can internalize and use to designate resources in the economy efficiently. The first market failure (the inter-temporal-spillover effect) occurs because entrepreneurs are unable to internalize the fact that their R&D efforts have a positive externality; they help future entrepreneurs either imitate or invent new products. The second market failure (the consumer-surplus effect) occurs because entrepreneurs do not internalize the fact that consumers benefit from product variety. The third market
failure (the profit-destruction effect) occurs because entrepreneurs are unable to recognize the fact that their R&D efforts and creation of new product varieties erodes the profits of other entrepreneurs, who will eventually enter the market.

The consumer-surplus effect and the profit-destruction effect cancel each other out. The failure to internalize the inter-temporal-spillover effect is what leads to a decentralized growth rate that is less than the growth rate that is achieved by the social planner. Because of these market failures, the government can intervene in the economy in order to achieve the growth rate of product varieties that is efficient. As is typical with most models that have market distortions, the government can subsidize R&D, or it can subsidize manufacturing. One novel feature my model has is that other endogenous growth models of technology diffusion do not have is that I can investigate subsidies to health and education as well because I have included the efficiency of labor as well as a learning to innovate process in my model.

2.5.1 Subsidies to R&D

One of the ways that the government can intervene in the economy in order to achieve the Pareto optimal result in a free market economy is by using a lump-sum tax to finance a subsidy to R&D. If the government subsidizes R&D by paying a portion \( \phi_R \) of all research expenses, entrepreneurs have an incentive to invent more products; thereby, increasing the growth rate of varieties. With government intervention, the free entry condition becomes

\[
\begin{align*}
    v_i &= \frac{(1-\phi_R)w}{\alpha N_B} \quad (2.33) \\
    v_i &= \frac{(1-\phi_R)w}{\beta N_B} \quad (2.34)
\end{align*}
\]

for entry by imitation and innovation respectively. The no-arbitrage condition is \( r = \frac{\pi_i}{v_i} + \frac{\hat{\pi}}{\hat{v}_i} \). Using the fact that \( r = \rho, \frac{\hat{\pi}}{\hat{v}_i} = g_{NB}, \frac{\pi_i}{v_i} = \frac{\alpha L E}{(1-\phi_R)\eta w}, \frac{\pi_i}{v_i} = \frac{\beta L E}{(1-\phi_R)\eta w}, X = \frac{L E (\eta-1)}{\eta w} \), and
multiplying by \( \frac{(\eta - 1)}{(\eta - 1)} \) yields

\[
\frac{\alpha X}{(1-\phi_R)(\eta-1)} = g_{NB} + \rho
\]

(2.35)

\[
\frac{\beta X}{(1-\phi_R)(\eta-1)} = g_{NB} + \rho
\]

(2.36)

for the no arbitrage conditions with government intervention, while (2.25) and (2.32) represent the no arbitrage condition for the decentralized equilibrium. The subsidy causes the NA curve to rotate clockwise to the right, but leaves the RC curve unchanged. With the subsidy to R&D, entrepreneurs have an incentive to enter the markets with more product varieties because the subsidy lowers entry costs. In other words, the subsidy increases the growth rate of product variety until the decentralized growth rate is equal to the Pareto optimal growth rate. It is easy to calculate the subsidy \( (\phi^*_R) \) that is needed to rotate the NA curve sufficiently enough to achieve the efficient growth rate for the economy. Plugging equations (2.15) and (2.26) into the no arbitrage conditions for imitation and innovation respectively yields

\[
\phi^*_R = 1 - \frac{\alpha(L - g_{NB})}{(\eta - 1)(g_{NB} + \rho)}
\]

(2.37)

\[
\phi^*_R = 1 - \frac{\beta(L - g_{NB})}{(\eta - 1)(g_{NB} + \rho)}
\]

(2.38)

Substituting for \( g_{NB}^* \) yields

\[
\phi^*_R = 1 - \frac{\rho}{L\alpha - (\eta - 1)\rho + \rho} = \frac{g_{NB}}{g_{NB}^* + \rho}
\]

(2.39)

\[
\phi^*_R = 1 - \frac{\rho}{L\beta - (\eta - 1)\rho + \rho} = \frac{g_{NB}}{g_{NB}^* + \rho}
\]

(2.40)

as the subsidy to R&D that is needed to achieve Pareto efficiency in the decentralized economy. With this subsidy, entrepreneurs are enticed to enter the market at the rate that is Pareto optimal and leads to both dynamic and static efficiency.
2.5.2 Subsidies to Manufacturing

Besides subsidizing R&D, the government can also subsidize manufacturing with a lump-sum tax. It is assumed that $\phi_X$ is the ad valorem rate of the subsidy to manufacturing. With this policy, manufacturers receive $P_{iX}(1 + \phi_X)$ for each unit of output that is sold, but consumers pay $P_{iX} \frac{w\eta}{(\eta-1)(1+\phi_X)}$ for each unit of output. The free entry condition does not change, but now profits for the firm are $[P_{iX}(1 + \phi_X) - w]X_i$ and $X = \frac{LE(\eta-1)(1+\phi_X)}{\eta w}$. The no arbitrage condition is

$$\frac{\alpha LE(1+\phi_X)}{w\eta} = gN_B + \rho$$
$$\frac{\beta LE(1+\phi_X)}{w\eta} = gN_B + \rho$$

which simplifies to

$$\frac{\alpha X}{(\eta-1)} = gN_B + \rho$$
$$\frac{\beta X}{(\eta-1)} = gN_B + \rho$$

and is exactly equal to what is obtained with the decentralized equilibrium. The subsidy to manufacturing has not provided any incentive for entrepreneurs to increase the growth rate of either imitated or innovated product varieties, so the decentralized equilibrium growth rate remains constant even after the subsidy to output. The reason why the growth rate is constant is because the government’s subsidy not only augments manufacturing, but it also augments research at the same time. Because of this, entrepreneurs, who need researchers, and established firms that need labor for manufacturing compete for workers and bid up the wage rate. A subsidy to manufacturing is ineffective because wages increase; therefore, it ends up not promoting R&D nor manufacturing.
2.5.3 Subsidies to Education and Health

One of the main contributions my research makes to the literature is the fact that I can analyze what effect subsidies to education and health have on the growth rate of product varieties because I have endogenized the efficiency level of the workforce. As shown earlier, if the government subsidies education or health, the growth rate increases. This means that with my model, besides subsidies to R&D and manufacturing, the government can make the decentralized result Pareto optimal by subsidizing education and health as well. Figure 2.7 illustrates what happens to the economy when the government intervenes by subsidizing health and education.

![Diagram illustrating the effect of subsidies to education and health on the growth rate of product varieties.]

Once again, the assumption is made that the government intervenes in the economy with a lump-sum tax and education and health adjust immediately, so the efficiency of labor adjusts immediately without diffusion lags as well. With government intervention, workers become
more efficient at R&D. This changes the slope of the RC line and shifts it out. This shift is represented by the RC’ curve. The NA curve also rotates clockwise to the right and is represented by the NA” curve. It is possible for the government to increase the growth rate sufficiently enough by subsidizing education and health so that the decentralized equilibrium becomes Pareto optimal. This is represented by $E^*$ in figure 2.7. The optimal values for $\alpha$ and $\beta$ are

$$\alpha^* = \frac{\rho(1-2\eta+\eta^2)}{L(\eta-1)}$$  \hspace{1cm} (2.43)
$$\beta^* = \frac{\rho(1-2\eta+\eta^2)}{L(\eta-1)}$$  \hspace{1cm} (2.44)

If the government intervenes in the economy and raises $\alpha$ and $\beta$ until they are equal to (2.43) and (2.44) then the efficient growth rate is achieved for the economy. The benefits of increasing education and health are twofold. First, the subsidy is a one-time occurrence and does not have to continue. Once $\alpha$ and $\beta$ have increased sufficiently enough, the government can stop subsidizing both. The second most important benefit to increasing health and education is the fact that it increases consumer welfare. The reason for this is that workers become more efficient at R&D, so more products are invented and imitated. Consumers love variety and an increase in variety increases utility. When R&D workers are more efficient, not only does the growth rate increase, but output increases as well. Consumers have the growth rate they want under the social planner, and they have the added benefit of being able to purchase more because of the increase in output.
2.6 Conclusion

This chapter investigates how government intervention in the economy can affect whether a
developing country transitions from imitating to innovating new products. It analyzes how
the government can intervene in the economy to raise the efficiency level of workers and
the effect this will have on the decisions of firms to either imitate or innovate in the steady
state. It also assesses the Pareto optimality of the steady state results of the decentralized
economy that were obtained in chapter 1 and compares the free market equilibrium results
to Pareto optimal equilibrium results.

What I find is that the government can influence whether firms invest in imitation or im-
itation by either increasing the education level of the workforce or by increasing the health
of the workforce. If the efficiency of the workforce that conducts innovation based R&D
increases sufficiently enough to make innovation more profitable than imitation, then a de-
veloping country that imitated only will transition from imitating a more advanced country’s
products to inventing its own products.

I also find that the decentralized equilibrium results are not Pareto optimal. The reason
for this is because there are three market distortions that affect the growth rate under the de-
centralized equilibrium that the social planner can internalize and use to designate resources
in the economy efficiently. The first market failure (the inter-temporal-spillover effect) oc-
curs because entrepreneurs are unable to internalize the fact that their R&D efforts have a
positive externality; they help future entrepreneurs either imitate or invent new products.
The second market failure (the consumer-surplus effect) occurs because entrepreneurs do
not internalize the fact that consumers benefit from product variety. The third market fail-
ure (the profit-destruction effect) occurs because entrepreneurs are unable to recognize the
fact that their R&D efforts and creation of new product varieties erodes the profits of other entrepreneurs, who will eventually enter the market. The consumer-surplus effect and the profit-destruction effect cancel each other out. The failure to internalize the inter-temporal-spillover effect is what leads to a decentralized growth rate that is less than the growth rate that is achieved by the social planner.

The Pareto optimal result can be achieved; however, if the government intervenes in the economy. If the government subsidizes R&D, or it increases the average education and health levels of the workforce, entrepreneurs have an incentive to enter the market at a faster rate, so the decentralized equilibrium growth rate increases until it becomes the Pareto optimal growth rate. The government should avoid subsidizing manufacturing because this has no effect on the growth rate of product variety. With a subsidy to output, entrepreneurs and manufacturers compete for labor and drive the market wage up. Thus, the subsidy is absorbed by workers, who earn higher wages. The growth rate remains constant; hence, a subsidy to output still does not produce the Pareto optimal result. The most interesting result of this chapter is the fact that if the government subsidizes health and education, not only is the Pareto optimal result achieved, but welfare increases as consumers can consume more of each good without sacrificing variety. This means that if a developing country wants to increase welfare as well as grow at its optimal growth rate, it should focus on increasing the education and health of its workforce. An added benefit to increases in the health and education of workers is the fact that once the optimal level has been achieved, the government can stop intervening in the economy.
Chapter 3

The Impact of Trade Liberalization on Technology Diffusion

3.1 Introduction

While the previous chapter focused on government intervention in the economy in the context of a theoretical model, and how this intervention impacts growth and TFP, this chapter focuses on government intervention in the economy in the context of an empirical model. In this chapter, government intervention occurs through policies that affect trade; thereby, influencing the opportunities firms have to acquire technology from abroad. In the mid-1980s, Mexico experienced a period of reform that opened its markets and facilitated trade with the rest of the world.

Using plant-level data from Mexico and data on input and output tariffs as well as license coverages, I research the effect of trade reform on the diffusion of technology. While there are many channels of technology diffusion, the channel that I choose to investigate is how technology diffuses in disembodied form through the purchase of patents and licenses. According to eurostat\(^1\), “the acquisition of disembodied technology includes acquisition of

\(^1\)This definition can be found at www.eurostat.ec.europa.eu
external technology in the form of patents, non-patented inventions, licenses, disclosure of know-how, trademarks, designs, patterns and computer and other scientific and technical services related to the implementation of TPP innovations, plus the acquisition of packaged software that is not classified elsewhere.” The fact that technology diffuses in disembodied form with the purchase of licenses and patents is generally recognized as an important channel of technology transfer, but, to date, no one has researched the effect of trade liberalization on the purchase of patents and licenses by domestic firms in a developing country. Typically, research concerning technology diffusion focuses on imports of intermediate and final goods as the conduit for the acquisition of disembodied technology by a developing country.

Odagiri (1983) is the first paper to suggest that researchers needs to investigate in-house R&D and royalty payments separately. He argues that “because firms can make a choice between making research themselves and acquiring licenses for outside patents, royalty payments should be considered as an alternative means of paying for research; hence, it is more logical to include royalty payments as an alternative R & D variable (62).” Even though the focus of Odagiri’s paper is not trade, his belief that royalty payments should be investigated separately from in-house R&D is logical and has influenced my research. He finds that it is important to separate in-house R&D from royalty payments because they affect sales growth differently; an outcome that is obscured if the econometrician does not distinguish between the two channels of acquiring technology.

Royalty payments are also an acceptable proxy for technology diffusion i.e. technology transfer which is what I am interested in researching. Lee Branstetter et al. (2006) state that they use “affiliate-level data on U. S. multinational firms and aggregate patent data to test whether legal reforms that strengthen IPR (intellectual property patent reform) increase
the transfer of technology to multinational affiliates operating in reforming countries. We find that royalty payments for the use or sale of intangible assets made by affiliates to parent firms, which reflect the value of technology transfer, increase in the wake of strengthened patent regimes (322).” Keller (2004) also states that royalty payments are an easily obtained, direct measure of international technology diffusion. He states that royalty payments reflect the international diffusion of technology that occurs through market transactions.

The literature on trade liberalization and its effects on technology transfer, growth, and productivity is expansive and quite impressive, but less research has been conducted concerning trade liberalization and innovation. According to Gorodnichenko et al. (2010), “innovation is a presumed conduit through which globalization affects productivity, yet there is little research testing the relationship between globalization and innovation (195)” in developing countries. To date, no consensus has been reached concerning the effect of trade liberalization on innovation. Most economists agree that the technology transfer and added competition that occurs with trade liberalization impacts the decision to innovate that occurs at the firm-level; however, some economists disagree about whether that impact is positive or negative.

The lack of research and a consensus concerning trade and technology adoption in emerging economies is what motivated me to investigate the issue. Using panel-level data on Mexican firms that was obtained from 1984-1990, I investigate how trade liberalization affects the amount that firms are willing to pay for patents, licenses and trademarks. To the author’s knowledge this is the first study that investigates the effect of both input and

2Gorodnichenko, Bustos (2011), Teshima (2010), and Aghion et al. (2005) provide an excellent overview of the literature concerning trade liberalization and its effects on innovation.
3Iacovone (2009) asserts that more research needs to be conducting concerning what influences the purchase of technology and in-house R&D.
output tariffs and input and output license coverage on purchases of disembodied knowledge i.e. patents and licenses. Bustos (2011) lumps R&D together with royalty payments, Teshima only focuses on process and product innovation and excludes royalty payments and Gorodnichenko uses three different measures of technology and also does not specifically study royalty payments. My research clearly makes a contribution to the literature and the ongoing discourse on the effects of trade liberalization on innovation within domestic firms in developing countries.

3.2 Background and Previous Literature

Much research has been conducted concerning trade and its impact on developing countries. After Rodrik (1988), Pack (1988) and Bhagwati (1988) pointed out that the empirical evidence supporting the purported theoretical benefits of trade liberalization was in existent, economists began to focus their attention on earnestly studying the effects of free trade in order to determine if trade liberalization is beneficial to developing countries or not. In the beginning, much of the research focused on trade, economic growth, and income. The research that focused on investigating the effect of trade liberalization on income usually only looked at the level effects of trade on income, while the research that was geared toward investigating the effect of trade on economic growth predicted that trade liberalization affects growth rates.

Sachs and Warner (1995) published an empirical paper that studied trade, income convergence, and economic growth. Both authors studied data on developing countries and conclude that those countries that had liberalized trade experienced higher growth rates than those countries that had instead opted to erect barriers to free trade. They also conclude that
the income of countries with liberalized trade was higher than the income of countries that hindered free trade.

Grossman and Helpman (1991d) develop a theoretical model to investigate the effects of trade liberalization on growth and find that a special case exists where increased trade leads to an increase in growth for a developing country. They reason that trade facilitates technology diffusion which serves as a catalyst for growth. G-H state “international trade in tangible commodities facilitates the exchange of intangible ideas (2).” According to their model, when ideas are transmitted by liberalizing trade, this increases the growth rate of the less developed country. Frankel and Romer (1999) research the effect that trade has on income and conclude that trade has a positive effect on income per capita. Ben-David and Loewy (1998) also study the effect of trade liberalization on output and growth rates. Their theoretical model and simulations show that liberalized trade leads to higher growth rates in developing countries. The authors agree with the theory of (G-H) and assert that the increase in growth rates is caused by the increase in technology diffusion that occurs with free trade. They state “the notion that the dissemination of ideas is essential to the growth process would seem to be fairly intuitive. Hence, any mechanism that might advance the flow of knowledge from one country to the next should provide a positive, or at least a non negative, spur to the development of countries (5).”

The second major area of research that has been conducted concerning trade deals with the effect of trade openness on the diffusion of technology and productivity. It is generally accepted that trade liberalization can impact productivity and efficiency at the aggregate, firm, and industry level. Some economists assert that the increased competition that is caused by opening up protected markets to international trade, causes domestic firms to increase their X-efficiency in order to survive. This means that domestic firms begin to
optimize production and resources and remove inefficiencies. As inefficient firms exit the market and resources are reallocated, productivity increases as well. Another reason why trade liberalization can have an impact on productivity is the fact that plants have more incentives to invest in technology that increases productivity after impediments to free trade are removed as long as they do not lose market share. The last reason that is typically given for how trade liberalization can affect productivity is the fact that liberalization allows firms to purchase higher quality inputs and capital goods, which increase productivity.

Tybout, Mello, and Corbo use two industrial censuses that were conducted in Chile to investigate the effect the trade liberalization of 1974-79 had on the efficiency of each industry. The authors find that the industries that become more productive relative to the remaining industries were the ones that had to cope with a drastic reduction in trade protection. Tybout and Westbrook (1995) examine plant level data from Mexico and find that the trade liberalization that occurred between 1984-1990 and find that productivity increased in most manufacturing industries. Tybout (2000) revisits the issue of trade liberalization and productivity, and he concludes that free trade does increase the efficiency of firms.

Coe, Helpman, and Hoffmaister (1995) research the effect of trade on technology diffusion and TFP. The authors find that the stock of foreign R&D capital, the stock of domestic R&D capital and domestic TFP are cointegrated. The authors then expand their analysis of trade and technology to include the transfer of technology from more advanced countries to less developed countries. In their 1997 paper, they conclude that there exists a significant amount of technology transfer from more advanced countries to less developed countries. Coe, Helpman and Hoffmaister also find that technology diffusion is highest when countries

\footnote{After Keller challenges the results that were found in this paper, the authors use new panel cointegration techniques and an expanded data set in a revised paper (2008) that substantiates all of the initial claims of the original paper.}
have policies in place that facilitate free trade, and they find that technology diffusion has a positive impact on TFP. Ferreira and Rossi (2003) use industry level data from Brazil to investigate the effect that trade liberalization has on TFP. The authors find that reducing trade barriers not only increases the growth rate of TFP, but it also increases labor productivity. They estimate that the tariff reductions that Brazil initiated between 1988-1990 led to a 6% increase in the growth rate of TFP.

Nina Pavcnik (2002) incorporates firm exit in her model and investigates the effect of trade liberalization on firm productivity in Chile from 1979-1986. She divides firms into the following three groups: import competing, exporting and non-traded goods oriented. She finds that the least amount of growth occurred in the non-traded sector, while most growth of productivity occurred in the import competing plants. She attributed this growth to a decrease in X-inefficiencies, less productive firms exiting the market, the reallocation of resources, and the adoption of better technology.

Ana Fernandes (2007) uses panel data on Colombian manufacturing plants from 1977-1991 to investigate whether trade liberalization positively affects productivity. Instead of using the indirect approach to estimate her results, Fernandes introduces a direct approach instead; arguing that her method produces unbiased estimators. She concludes that trade liberalization does increase productivity because firms are enticed into investing in machinery, they import more advanced intermediate inputs, and resources are efficiently reallocated from less to more productive plants.

Amiti and Konings (2011) is one of the first set of empirical papers to investigate the effects of lowering tariffs on both intermediate inputs and final goods. Both authors assert that it is important to investigate the effects of input and output tariffs instead of just focusing on output tariffs because empirical tests that only include output tariffs suffer from
having an omitted variable bias. They use census data on manufacturing that was taken in Indonesia from 1991 to 2001 to test the following hypotheses: that decreasing output tariffs increases productivity in the domestic country because firms have to compete with more efficient foreign firms; while, lowering input tariffs increases productivity in the domestic country as domestic firms have cheaper and easier access to the advanced technology that is embedded in imported goods. They find that lowering input and output tariffs increases firm-level productivity with the biggest gains in productivity coming from lowering input tariffs. Topalova and Khandelwal (2011) also research the effects that lowering input and output tariffs has on firm level productivity. They use data from India and reach the same conclusions as Amiti and Konings.

The third strand of research in the literature involves investigating the effect that trade liberalization has on a firm’s incentive to invest and innovate. This strand of literature is more recent for developing countries, and the effects of trade liberalization on the investment and innovation decisions of firms has not been researched as thoroughly as the effects of trade liberalization on growth and productivity. This third strand of literature provides the motivation for my research. Kandilov and Leblebicioğlu (2011) use firm-level panel data from Mexico to investigate the effect that lowering input and output protection has on investment. Their empirical results substantiate the theory that lowering input protection increases firm-level investment because firms become more profitable since they can import cheaper imports; while, lowering output protection discourages investment because firms become less profitable as they have to compete with foreign firms. Although I am interested in investigating the effects of trade liberalization on technology transfer in disembodied form, and Kandilov and Leblebicioğlu investigate the effects of trade liberalization on investment, their research question peaked my curiosity to research the effects of trade
The three studies that are most similar to mine are Bustos (2011), Teshima (2010), and Gorodnichenko et al. (2010) because these authors focus specifically on answering the question: does trade liberalization encourage investment in acquiring new technology by firms? Bustos examines the effect that tariff reductions by a trading partner (in the context of MERCOSUR) have on technology upgrading. Using firm-level data from Argentina, Bustos shows that trade liberalization by a trading partner i.e. Brazil encourages some firms to adopt new technologies. She divides the firms into three groups after trade liberalization: continuing exporters, new exporters and non exporters. She finds that the continuing exporters have already invested in adopting new technologies before trade liberalization; the new exporters will invest in adopting new technologies after trade liberalization, while non exporters will not. Bustos’ research is novel in the fact that she has direct and comprehensive information from firms about how much they spend on “computers, software, technology transfers, patents, and innovation activities performed within the firm like research and development (305).” This means that her empirical analysis is more precise because she does not have to use proxies to estimate the level of technology per firm.

The shortcoming of Bustos’ analysis is made apparent by the work done by Teshima. Instead of summing up spending on several types of technology, Teshima separates spending on innovation\(^5\) into both product and process innovation. He uses plant-level panel data from Mexico to study the effect that lowering output tariffs has on R&D. Similar to Bustos, Teshima has direct and comprehensive information about how much firms spend on product and process innovation. In his first estimation, Teshima groups product and process innova-

\(^5\)Bustos eventually separates innovation into product and process innovation as well, but she does not use spending on innovation as the control variable. She uses binary responses of yes or no from firms as to what type of spending they had made during the year. Her conclusions are similar to Gorodnichenko’s.
tion together and finds that a reduction in tariffs encourages firms to invest in R&D. In his next estimation model, Teshima separates product and process innovation\(^6\) and finds that a reduction in tariffs encourages firms to invest in process R&D that enables them to become more efficient and lower costs, but there is no evidence to substantiate the fact that trade liberalization encourages firms to invest in product R&D. In light of Teshima’s findings, it can be concluded that research that uses a total measure of investment in technology instead of looking at each different type of acquisition of technology individually, can lead economists to make incorrect inferences.

Gorodnichenko also separates the different types of technology and R&D. The authors use three categories to describe the innovative activities of firms in fifteen emerging economies in central and eastern Europe: new product, new technology, and new accreditation. Unlike Teshima, they find a strong positive relationship\(^7\) between trade liberalization and all three types of innovation. My research focuses on investigating how trade liberalization affects the amount that firms are willing to pay for patents, licenses and trademarks. Not only do I use input and output tariffs as measures of trade openness, but I also use estimates of license coverage for both inputs and outputs.

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\(^6\)Teshima’s results prove that not only was Ogadiri correct in asserting that R&D needed to be separated from royalty payments in estimation models, but the effect of trade liberalization on different forms of R&D needs to be investigated separately as well.

\(^7\)It should be noted that Teshima uses expenditure on innovation, while Gorodnichenko uses binary variables to illustrate whether firms answered yes or no to the fact that they had undertaken innovative activities.
3.3 The History of Trade Liberalization in Mexico

Prior to the massive trade liberalization that began in 1985, the Mexican government pursued a very protectionist policy\textsuperscript{8} for the economy. Similar to other Latin American countries, the government in Mexico was influenced by the ideas of Raul Prebisch. Prebisch (1959) declared, “industrialization needs a dynamic policy of protection, which should be continually adapted so as to introduce new changes in import composition as the economy develops...”\textsuperscript{(269)} By 1960, the government had initiated several import substitution policies that were aimed at promoting the domestic production of inputs used in production as well as consumer goods to replace foreign imports. Most of the sectors that were promoted included non-durable consumer goods, durable consumer goods, light intermediate goods, heavy intermediate goods, and capital goods.

When the Mexican government first started its policy of import-substitution, tariffs were the main deterrent to international trade. During the sixties, the government relied more on import licenses to protect its domestic industries from foreign competition, and import licenses were distributed based on whether something was domestically available or not. The government also initiated the policy of domestic content requirements and disseminated lists of products it believed should be substituted in the future. It was also during this time that the government started the maquiladora (subcontracting) program. Firms in the maquiladora industry benefited from special free trade and investment incentives that were given to them by the government. During the seventies, the government began to promote exports by giving exporting firms subsidies and offering them tariff rebates on their imported inputs. The government also increased the number of export credits it provided to firms and created

\textsuperscript{8}This overview of the history of trade liberalization is taken from Weiss (1999), Ten Kate (1992), and Ros (1993).
FONEI (Fondo de equipamiento industrial) and IMCE\textsuperscript{9} (Instituto Mexicano de Comercio Exterior).

Since the macroeconomic environment in Mexico was favorable and the economy was doing quite well before the instability that occurred in the seventies and early eighties, import substitution was viewed as being successful. During the seventies and early eighties; however, Mexico experienced inflation, exchange rate volatility, an oil price crisis and balance of payments problems which forced it to reconsider its protectionist policies of import substitution. Due to the growing concern with the lack of growth in the economy, the government decided to privatize industries, cut spending, encourage FDI, and stabilize prices.

The most drastic policy undertaken by the government was its decision to liberalize markets. John Weiss (1999) states that “The programme of trade reform introduced in Mexico in the period 1985-87 was one of the most far-reaching of any developing economy. In a relatively brief period import quota restrictions were removed for most goods, and import duties were lowered to an average of around 10 per cent (151).” Table 3.1\textsuperscript{10} illustrates the evolution of the trade liberalization that took place in Mexico. As can be seen from the table, both input and output license coverage declined in most industries to close to 0 per cent by 1989. Input and output tariffs decreased as well. For most industries, output tariffs decreased to around 10-20 percent, while input tariffs decreased to around 10 percent by 1989.

\textsuperscript{9}Both agencies were created to promote the export industry in Mexico by giving firms access to financing, etc.

\textsuperscript{10}Table 3.1 is used with permission from Ivan Kandilov and Asli Leblebicioğlu.
Table 3.1 Tariff and License Coverage Rates

<table>
<thead>
<tr>
<th>Industry</th>
<th>Output Tariff</th>
<th>Output License</th>
<th>Input Tariff</th>
<th>Input License</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food, Beverages, Tobacco</td>
<td>41 30 16</td>
<td>100 45 22</td>
<td>19 19 11</td>
<td>55 59 30</td>
</tr>
<tr>
<td>Textile, Apparel and Leather</td>
<td>40 37 17</td>
<td>93 37 1</td>
<td>29 30 13</td>
<td>84 11 3</td>
</tr>
<tr>
<td>Products</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood and Paper Products</td>
<td>36 33 11</td>
<td>97 9 3</td>
<td>26 25 10</td>
<td>90 16 5</td>
</tr>
<tr>
<td>Chemicals and Plastics</td>
<td>30 29 14</td>
<td>87 10 0</td>
<td>21 20 11</td>
<td>81 16 10</td>
</tr>
<tr>
<td>Non-metallic Products</td>
<td>32 28 13</td>
<td>95 0 0</td>
<td>22 21 12</td>
<td>73 12 8</td>
</tr>
<tr>
<td>Basic Metals</td>
<td>8 15 10</td>
<td>95 0 0</td>
<td>15 16 11</td>
<td>75 2 2</td>
</tr>
<tr>
<td>Metal Products, Machinery and</td>
<td>45 28 16</td>
<td>93 55 45</td>
<td>22 26 13</td>
<td>91 13 4</td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Manufacturing</td>
<td>37 36 18</td>
<td>100 0 0</td>
<td>27 25 12</td>
<td>88 18 9</td>
</tr>
<tr>
<td>Total Manufacturing</td>
<td>57.09 28.86 14.79</td>
<td>93.78 30.58 18.92</td>
<td>21.64 22.18 11.78</td>
<td>77.50 23.47 13.46</td>
</tr>
</tbody>
</table>

Note: All figures are percentages. The output and input tariffs are exclusive of the 5% official tariff surcharges.

Source: unpublished data provided by Adrián Ten Kate, SECOFI

3.4 The Data

The source of the plant-level data are confidential annual surveys that were carried out by the National Institute of Statistics and Geography (INEGI) in Mexico. During the time that INEGI collected the data, the Mexican government initiated and concluded a broad policy of trade liberalization. The data from these surveys was made available by Mexico’s Secretariat of Commerce and Industrial Development (SECOFI). The data covers the years 1984-1990 and provides information on almost 100 variables such as revenues, costs, employment, wages, exports, imports, ownership, etc. The data is collected at the plant-level, and each establishment is given a unique number, so that it can be identified and tracked over time. The government also assigns each plant to a manufacturing industry that is very similar to
the 4-digit International Standard Industrial Classification (ISIC).

The panel is balanced and was originally used by Tybout and Westbrook (1995). The data excludes small plants and maquiladoras. The maquiladora plants were excluded because they provide a subcontracting service and do not provide information regarding the value of gross output or intermediate inputs. The remaining plants represent about 80 percent of cumulative value added. Plants that did not report the value of sales or information concerning employees were eliminated; leaving a sample of 2,389 plants covering seven years. All monetary variables were converted into millions of 1980 Mexican pesos using the appropriate price\textsuperscript{11} deflators. All of the data with respect to the 4-digit industry input and output tariffs\textsuperscript{12} as well as input and output license coverage was calculated and provided by Adrian Ten Kate of Mexico’s Secretariat of Commerce and Industrial Development (SECOFI) and Tybout and Westbrook.

The tariff rates and license coverage rates are aggregate rates for each industry instead of plant specific rates. The aggregate rates for both input and output tariffs and input and output license coverage were calculated using two different methods. Output tariffs were aggregated by using weights for the domestic production of products manufactured within each industry and the product specific tariffs within each industry. The input tariff was calculated using the following formula:

\[ Input Tariff_{jt} = \sum_{s} \theta_{js} Output Tariff_{st} \]  

(3.1)

Where \( \theta_{js} \) represents the share of input \( s \) that is included in the value of output in industry \( j \). The output license coverage ratio is constructed as the share of goods that are subject to import licensing as a percentage of the value of that specific industry’s production. The

\textsuperscript{11}For more on this, please see Tybout and Westbrook.

\textsuperscript{12}The overview of the data source is taken from Kandilov and Leblebicioğlu.
input license coverage ratio is calculated in the same way as the input tariffs.

3.5 Model and Empirical Methodology

3.5.1 Estimation Model

I test the effect that trade liberalization has on technology diffusion using royalty payments as a proxy for technology diffusion and industry specific input/output tariffs and license coverage measures as proxies for trade openness. According to INEGI, plants are instructed to include the dollar amount that they spent on royalty payments during the year. Royalty payments are defined as payments made to a third party for the legal right to use patents, licenses, copyrights, or trademarks. Plants are advised that they should exclude any investments or payments they made toward their own in-house R&D. My baseline model is

\[
\frac{RP_{ijt}}{TE_{ijt}} = \beta_1 \frac{NWB_{ijt}}{TE_{ijt}} + \beta_2 \frac{SC_{ijt}}{TE_{ijt}} + \beta_3 \frac{AC_{ijt}}{TE_{ijt}} + \beta_4 \frac{SW_{ijt}}{TW_{ijt}} + \beta_5 \tau_{ijt}^{OT} + \beta_6 \tau_{ijt}^{OL} + \beta_7 \tau_{ijt}^{IT} + \beta_8 \tau_{ijt}^{IL} + \delta_t T_t + \mu_i + \epsilon_{ijt} \tag{3.2}
\]

Where \(\frac{RP_{ijt}}{TE_{ijt}}\) is the amount a specific plant \(i\) in industry \(j\) paid in royalty payments in year \(t\) normalized by the total number of employees; \(\frac{NWB_{ijt}}{TE_{ijt}}\) is the amount that was spent on non-wage benefits; \(\frac{SC_{ijt}}{TE_{ijt}}\) is the amount that was spent on sales commissions; and \(\frac{AC_{ijt}}{TE_{ijt}}\) is the amount that was spent on advertising. \(\frac{SW_{ijt}}{TW_{ijt}}\) is a quality measure of the workforce that is calculated by dividing total spending on white collar workers by total spending on both...
white collar and blue collar workers. The terms $\tau_{jt}^{OT} + \tau_{jt}^{OL}$ represent the output tariffs and output license coverage for industry $j$ in year $t$, while the terms $\tau_{jt}^{IT} + \tau_{jt}^{IL}$ represent the input tariff and license measure. The term $\delta_{jt}^T$ denotes a binary year dummy variable\textsuperscript{13} that is equal to one if an observation occurs in a given year and zero otherwise. $\mu_i$ is the plant-level effect, and $\varepsilon_{ijt}$ is the disturbance term i.e. idiosyncratic error term.

### 3.5.2 Summary Statistics

Approximately 18 percent of the 2,389 firms that are included in the sample made royalty payments during the years 1984-1990. Tables 3.2-3.5 list the summary statistics for each control\textsuperscript{14} variable. All monetary variables are measured in millions of 1980 Mexican pesos; thus 19, equals 19 million pesos. The input/output tariffs and license coverage are measured as percentages; thus, 32 equals 32 percent. The first table lists the summary statistics for all firms. Royalty payments, non-wage benefits, sales commissions, and imports machines are normalized by the total number of employees per firm. As already stated, royalty payments are defined as payments made to a third party for the legal right to use patents, licenses, copyrights, or trademarks. Non-wage benefits are payments made by the firm for services or goods that benefits its employees; excluding wages and salaries. Sales commissions are payments made to the firm’s sales force, and are typically a percentage that a salesperson receives from each sale made. Imports Machines represent the payments for capital goods that are imported by each firm. White collar salaries is a proxy for the quality (skill level) of the workforce. It is calculated by dividing the skilled wage bill by the total wage bill. Profit

\begin{footnotesize}
\textsuperscript{13}Since one year is excluded, there are t-1 time periods.
\textsuperscript{14}The control variables profit and imports machines are not included in the baseline model, but are included in two extensions of the model.
\end{footnotesize}
is a crude measure of sales profit and is calculated by subtracting all of the variable costs (excluding sales commissions) and white collar salaries from total revenue. Profit is then normalized by the total number of employees per firm. Input tariffs, input license coverage, output tariffs, and output license coverage are measured as percents.

I then divide the firms into three groups: small, medium, and large based on the number of employees per firm. Tables 3.3-3.5 report the summary statistics per firm size. As expected, large firms and medium sized firms tend to spend substantially more money on average on royalty payments, non-wage benefits, advertising, and importing machines than small firms. Large firms are significantly more profitable on average than medium sized and small firms. All three firms spend similar, average amounts of money on sales commissions and white collar salaries. The average input and output tariffs and input and output license coverage rates are also similar; with large firms facing slightly higher input and output tariffs and output license coverage.
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Table 3.3 Summary Statistics: Large Firms

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<td>Output Tariffs</td>
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<td>-1.2</td>
<td>77.13</td>
<td></td>
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<td>-7.5</td>
<td>83.85</td>
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<td>Min</td>
<td>Max</td>
<td>Observations</td>
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</tr>
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<td>6.56</td>
<td>2.8</td>
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<td>33.36</td>
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<td>96.66</td>
<td></td>
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<td>100.00</td>
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<td>42.55</td>
<td>-32.0</td>
<td>115.45</td>
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</table>
3.5.3 Estimation Strategy

Due to the fact that I use panel data, there are three types of estimation techniques that I considered in order to estimate my model: pooled OLS, fixed effects (FE), and random effects (RE). Pooled OLS is the simplest of the three models. The data for all firms is simply pooled together and a simple OLS regression is run. Pooled OLS is the suitable model to use if firm specific heterogeneity does not exist. I ran an F test\(^\text{15}\) of the null hypothesis that there was no firm level heterogeneity, and the null hypothesis was rejected\(^\text{16}\) at a 1% significance level. This means that using pooled OLS is inappropriate because such a regression would provide inconsistent estimates.

Since firm specific heterogeneity does exist, then either the FE or RE models are appropriate models to use. Both models control for differences between the firms that cannot be observed or measured and are time invariant i.e. management practices. They also control for macroeconomic conditions that change over time and have the same effect on each firm. The only difference between the RE and FE models is the assumption that is made in the RE model that the regressors are not correlated with the unobserved, heterogeneous, firm effects. In order to decide between using either the RE or FE model, I run a Hausman test of the baseline model. The null hypothesis of the Hausman test is that the the unobserved effects are not correlated with the regressors. The Hausman test resulted in a $\chi^2$ statistic of 105.95 that has a p-value of 0.0000. The null hypothesis is rejected at a 1% significance level, so the FE model is the appropriate model to use because the RE estimator is inconsistent. I then check to see if the time effects are needed in the FE model. The null hypothesis is that the time effects are jointly insignificant. The regression results in an F statistic of 2.41

\(^{15}\)Stata was used to run all the regressions, and this F test was run on the baseline model.
\(^{16}\)The regression resulted in an F statistic of 7.29 that has a p-value of 0.0000
with a p-value of 0.0254, so the null hypothesis is rejected at a 5% significance level. This means that the time-fixed effects are jointly significant and should be included to ensure that the model is properly specified.

### 3.5.4 Diagnostic Tests

Two important assumptions that the FE model makes is that the variance of the idiosyncratic error terms are homoskedastic, and the idiosyncratic error terms are uncorrelated. Before I can make any statistical inferences, I need to check for heteroskedasticity (HK) and cross-sectional correlation of the idiosyncratic errors. The presence of HK and cross-sectional correlation lead to inconsistent estimates and biased standard errors that make accurate statistical inferences impossible. Stock and Watson (2008) show that the traditional heteroskedasticity-robust estimator is inconsistent for most panel datasets if the time periods remain constant, while the number of entities increases. They provide a heteroskedasticity-robust estimator that is currently supported by Stata. I use the method proposed by Baum (2006) to conduct a modified Wald test to check for HK. The null hypothesis is that the variance of the idiosyncratic errors are constant. The modified Wald test results in a $\chi^2$ statistic of 2.8e+10 that has a p-value of 0.000, so the null hypothesis is rejected at a 1% significance level; hence, HK is present.

I then test for serial correlation in the idiosyncratic errors using the method proposed by Woolridge (2002). The null hypothesis is that there is no serial correlation. Woolridge’s Test results in an F statistic of 55.8 that has a p-value of 0.000. This means that the null hypothesis is strongly rejected, so the data does have serial correlation. The results of both tests mean that I will need to use the Stock and Watson HK-robust standard errors as well.
as clustering at the panel level in order to obtain consistent estimates of the standard errors and make statistical inferences.

Now that I know to use the FE model with time effects and to correct for HK and serial correlation, I run the first regression on the baseline model (model 1) from equation (1). After obtaining the results from model 1, I run the regression on the following models, which I designate as models 2 and models 3 respectively:

\[
\frac{RP_{ijt}}{TE_{ijt}} = \beta_1 \frac{NWB_{ijt}}{TE_{ijt}} + \beta_2 \frac{SC_{ijt}}{TE_{ijt}} + \beta_3 \frac{AC_{ijt}}{TE_{ijt}} + \beta_4 \frac{SW_{ijt}}{TW_{ijt}} + \beta_5 \frac{IM_{ijt}}{TE_{ijt}} + \beta_6 \frac{INT^IT_{jlt}}{TE_{ijt}} + \\
\beta_7 INT^IL_{jt} + \beta_8 \tau_{jlt}^{OL} + \beta_9 \tau_{jlt}^{OT} + \beta_{10} \tau_{jlt}^{IT} + \beta_{11} \tau_{jlt}^{IL} + \delta_i T_t + \mu_i + \varepsilon_{ijt} \quad (3.3)
\]

\[
\frac{RP_{ijt}}{TE_{ijt}} = \beta_1 \frac{NWB_{ijt}}{TE_{ijt}} + \beta_2 \frac{SC_{ijt}}{TE_{ijt}} + \beta_3 \frac{AC_{ijt}}{TE_{ijt}} + \beta_4 \frac{SW_{ijt}}{TW_{ijt}} + \beta_5 \frac{IM_{ijt}}{TE_{ijt}} + \beta_6 \frac{INT^IT_{jlt}}{TE_{ijt}} + \\
\beta_7 INT^IL_{jt} + \beta_8 \frac{PT_{ijt}}{TE_{ijt}} + \beta_9 \tau_{jlt}^{OL} + \beta_{10} \tau_{jlt}^{OT} + \beta_{11} \tau_{jlt}^{IT} + \beta_{12} \tau_{jlt}^{IL} + \delta_i T_t + \mu_i + \varepsilon_{ijt} \quad (3.4)
\]

The four regressors that are added to the baseline model are imports machines \((\frac{IM_{ijt}}{TE_{ijt}})\), two interaction terms \((INT^IT_{jlt}, INT^IL_{jt})\), and profit \((\frac{PT_{ijt}}{TE_{ijt}})\). Imports machines represent the payments for capital goods that are imported by each firm. Profit is a crude measure of sales profit and is calculated by subtracting all of the variable costs (excluding sales commissions) and white collar salaries from total revenue. Both imports machines and profit are normalized by the total number of employees per firm. The interaction term \((INT^IT_{jlt})\) interacts imports machines with import tariffs, and the interaction term \((INT^IL_{jt})\) interacts imports machines with the measure of license coverage for imports. Imports machines and both the interaction terms were added to investigate if there is a possible substitution or comple-
ment effect that occurs between royalty payments and imported capital goods. Based on the dataset that is used, true profit is difficult to measure, but a proxy variable for profit was added in order to investigate if profit affects royalty payments as well.

3.6 Estimation Results

3.6.1 Estimation Results: All Firms

I estimate equations (3.2)-(3.4) as a balanced panel with plant fixed effects for the period 1984 to 1990. The standard errors are robust and have been corrected for heteroskedasticity and serial correlation at the plant level. The results\(^\text{17}\) from estimating all three equations are presented in Table 3.6.

\(^{17}\)All of the monetary results are in millions of 1980 Mexican pesos. Thus a value of \(0.98 = 980,000\) Mexican pesos. According to the measuring worth website, the exchange rate between the USD and MXP in 1980 was 1 USD = 23.0 MXP.
Table 3.6 Results: All Firms

<table>
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<tr>
<th>Dependent Variable</th>
<th>Model (1)</th>
<th>Model (2)</th>
<th>Model (3)</th>
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<td>0.201**</td>
<td>0.192**</td>
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<td>(0.107)</td>
<td>(0.108)</td>
<td>(0.100)</td>
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<td>0.057**</td>
<td>0.055**</td>
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<tr>
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<td>(0.033)</td>
<td>(0.033)</td>
<td></td>
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<td>AdvC</td>
<td>0.229***</td>
<td>0.229***</td>
<td>0.225***</td>
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<td>(0.037)</td>
<td>(0.037)</td>
<td>(0.040)</td>
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<tr>
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<td>0.002*</td>
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<td>F test (p-value)</td>
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<td>0.000</td>
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Notes: Robust standard errors in parentheses. A set of year dummies are included in all specifications.

*** Significant at 5 percent.
** Significant at 10 percent.
* Significant at 20 percent.
The first column of Table 3.6 reports the results from Model 1. Only two measures of trade liberalization (output tariffs and output license coverage) have a significant impact on royalty payments. The coefficient on output tariffs is positive and significant. The estimated coefficient implies that a 10 percentage point decrease in output tariffs decreases royalty payments per employee by 50,000 Mexican pesos (MXP). In other words, a 10 percentage point decrease in output tariffs decreases average royalty payments per employee by 15.8 percent. The coefficient on the license coverage measure for outputs is also positive and significant. The point estimate implies that a 10 percentage point decrease in the license coverage measure decreases royalty payments per employee by 20,000 Mexican pesos (MXP). In other words, a 10 percentage point decrease in the license coverage measure decreases average royalty payments per employee by 6.3 percent.

There are two possible explanations for why royalty payments decrease when output tariffs and the license coverage measure decrease. The first explanation is the profit motive. It is a well known fact that firm-level profits decrease with trade liberalization. This means that when firms earn less profit, they spend less on purchasing technology i.e. royalty payments are considered an investment\(^\text{18}\). The second reason can be that firms view patents and licenses as substitutes (the substitution effect) for importing final goods. If it becomes less complicated (because there is no need to file a license application) or less expensive (because of lower output tariffs), then firms decide to purchase a product directly instead of buying a patent and making the product themselves. Both explanations are plausible.

As expected, the coefficients on non-wage benefits, sales commissions, and advertising costs are all positive and significant. Non-wage benefits and advertising costs have a bigger

\(^{18}\)Kandilov and Leblebicioğlu (2011) provide an excellent analysis of how trade liberalization and the profit motive affect firm-level investment.
impact on royalty payments than sales commissions. A one million MXP increase in advertising costs causes royalty payments to increase by 229,000 MXP; a one million MXP increase in non-wage benefits increases royalty payments by 198,000 MXP; and a one million MXP increase in sales commissions increases royalty payments by 57,000 MXP. Firms that can spend more on non-wage benefits and advertising are more likely to have more money to spend on royalty payments as well. The amount spent on sales commissions can reflect two different phenomena: product sales are good; or firms are able to offer their sales force a higher commission percentage. Thus, a firm that spends more on sales commissions should be able to spend more on royalty payments as well.

The coefficient on white collar salaries is not significant and is negative. It might be the case that when a firm buys a patent and know-how from a third party, it decreases the need to have a higher skilled workforce. It can also be the case that with a higher skilled workforce, firms prefer to conduct their own in-house R&D\textsuperscript{19} instead of purchasing technology, and this is why the coefficient is negative.

The negative coefficient on the license coverage measure for inputs, while not significant, also likely occurs because of the profit motive. When the input license coverage measure decreases, royalty payments increase because firm-level profitability increases. The positive coefficient on the input tariff, while not significant, is more in line with the substitution effect and not the profit motive. The issue that needs to be addressed is why the two input trade measures, although insignificant, have different signs. The most reasonable explanation for why the input license coverage measure has a negative coefficient and input tariffs have a positive coefficient is the fact that the substitution effect and profit motive work in the same direction with output tariffs and output licenses, but this is not the case with input tariffs and

\textsuperscript{19}Since the dataset did not include data on R&D; unfortunately, it is impossible to test this assumption.
input licenses. This is why the signs can be different because one effect might outweigh the other effect.

Before trade liberalization, a Mexican firm needed to fill out an application, submit it, and wait to be approved in order to obtain an import license. Licenses were usually granted solely based on the availability of domestic supplies of the same goods. This meant that if a good was available domestically, a license was not given to import it; therefore, firms had to buy the good from a domestic supplier. In the case of an input, this meant that firms had to pay higher, domestic prices. When the license requirements decreased for inputs, so that firms could freely import less expensive goods from abroad, costs decreased as well. This reduction in costs, led to an increase in profit. This increase in firm-level profit acts as an incentive to purchase technology; hence the sign of the coefficient is negative because the profit effect must be greater than the substitution effect. It can also be the case that inputs that had license coverage restrictions could not easily be substituted by a patent. The coefficient on input tariffs is positive which means that the substitution effect must dominate the profit motive. It can be the case that inputs that had tariff restrictions could be replaced with a patent much easier.

The profit motive that affects royalty payments is deduced from standard economic theory. The substitution effect that I propose is novel. It is an effect that can be tested to see if this theory is indeed correct. In order to test the hypothesis of a substitution effect, I include import machines as a control, and I include two interaction terms. Since both coefficients on output tariffs and output license coverage are significant and positive and the coefficient on input tariffs is positive and much larger than the negative coefficient on input license coverage, if there is a dominant substitution effect between royalty payments and capital goods

\[20\] See Ros (1993) for a detailed explanation of Mexico’s trade policy with respect to tariffs and licenses
imports, it should cause the coefficient on imports machines to be negative. I also need to
test the hypothesis about the different signs of the point estimates of input tariffs and input
license coverage.

If the profit motive causes the negative coefficient for input license coverage, then the
coefficient on the interaction term of input license coverage with imports machines should
be negative. This would mean that additional expenditure on imported capital will yield a
lower decrease in royalty payments the lower the input license coverage measure. This will
occur because the profit motive states that when the license coverage measure decreases,
firms have more money to spend on both royalty payments and imported capital. Thus,
even if imported capital and royalty payments are in fact substitutes, when there is a lower
input license coverage measure that increases profits, the decrease in expenditure on royalty
payments will be less.

If the substitution effect is what causes the positive point estimate for input tariffs, then
the coefficient on the interaction term of input tariffs with imports machines should be posi-
tive. This would mean that additional expenditure on imported capital will yield a higher
decrease in royalty payments the lower the input tariff. This will occur because the substi-
tution effect induces more firms to import capital goods instead of investing in purchasing
technology when import tariffs are low.

The second column of Table 3.6 shows the results from estimating equation (3.3). Even
though the point estimates for the three new control variables are not significant, and the
economic impact is quite small, the regression results are important and insightful. As
expected, the coefficient on imports machines is negative; the coefficient on the interaction
term of imports machines with import tariffs is positive; the coefficient on the interaction
term of imports machines with the import license coverage measure is negative. This means
that my hypotheses about the substitution effect and profit motive are correct, so model 1 is well specified. The fact that the other control variables maintain their significance and have roughly the same point estimates with the second regression provides further evidence that model 1 is well specified.

The third column of Table 3.6 shows the results from estimating equation (3.4) to control for profit. As already stated, it is quite difficult to obtain a good proxy for firm-level profits using the Mexican dataset. As expected, the coefficient is positive, but it is not significant and the economic effect is quite small. The fact that the other control variables maintain their significance and have roughly the same point estimates with the third regression provides further evidence that model 1 is well specified.

### 3.6.2 Estimation Results: Heterogeneity Across Firms

In order to empirically test to see if there is heterogeneity in the impact of Mexico’s trade liberalization on firm-level royalty payments, following Bustos (2011) and Kandilov and Leblebicioğlu (2011), I divide the firms into the following three groups based on the total number of employees each firm had in 1984: large, medium, and small. The initial size of the firm in 1984 is used as a proxy for initial productivity. I then estimated the following three models:

\[
\frac{\text{RP}_{ijt}}{\text{TE}_{ijt}} = \beta_1 \frac{\text{NW}_{ijt}}{\text{TE}_{ijt}} + \beta_2 \frac{\text{SC}_{ijt}}{\text{TE}_{ijt}} + \beta_3 \frac{\text{AC}_{ijt}}{\text{TE}_{ijt}} + \beta_4 \frac{\text{SW}_{ijt}}{\text{TE}_{ijt}} + \sum_{s=1}^{3} \gamma_{s}^{\text{OT}} (\tau_{ijt}^{\text{OT}} \times Q_{ij}^{s}) + \\
\sum_{s=1}^{3} \gamma_{s}^{\text{OL}} (\tau_{ijt}^{\text{OL}} \times Q_{ij}^{s}) + \sum_{s=1}^{3} \gamma_{s}^{\text{IT}} (\tau_{ijt}^{\text{IT}} \times Q_{ij}^{s}) + \\
\sum_{s=1}^{3} \gamma_{s}^{\text{IL}} (\tau_{ijt}^{\text{IL}} \times Q_{ij}^{s}) + \delta_t + \mu_i + \epsilon_{ijt}
\]  

(3.5)
\[
\frac{RP_{ij}}{TE_{ij}} = \beta_1 \frac{NW_{Bi_j}}{TE_{ij}} + \beta_2 \frac{SC_{ij}}{TE_{ij}} + \beta_3 \frac{AC_{ij}}{TE_{ij}} + \beta_4 \frac{SW_{ij}}{TE_{ij}} + \beta_5 \frac{IM_{ij}}{TE_{ij}} + \beta_6 \frac{INT^{IT}}{TE_{ij}} + \\
\beta_7 \frac{INT^{IL}}{TE_{ij}} + \sum_{s=1}^{3} \gamma_{TOT}^s (\tau_{ij}^{OT} \times Q_{ij}^s) + \sum_{s=1}^{3} \gamma_{TOL}^s (\tau_{ij}^{OL} \times Q_{ij}^s) + \\
3 \sum_{s=1}^{3} \gamma_{TIT}^s (\tau_{ij}^{IT} \times Q_{ij}^s) + 3 \sum_{s=1}^{3} \gamma_{TIL}^s (\tau_{ij}^{IL} \times Q_{ij}^s) + \delta_i T_i + \mu_i + \varepsilon_{ij}
\] (3.6)

\[
\frac{RP_{ij}}{TE_{ij}} = \beta_1 \frac{NW_{Bi_j}}{TE_{ij}} + \beta_2 \frac{SC_{ij}}{TE_{ij}} + \beta_3 \frac{AC_{ij}}{TE_{ij}} + \beta_4 \frac{SW_{ij}}{TE_{ij}} + \beta_5 \frac{IM_{ij}}{TE_{ij}} + \beta_6 \frac{INT^{IT}}{TE_{ij}} + \\
\beta_7 \frac{INT^{IL}}{TE_{ij}} + \beta_8 \frac{PT_{ij}}{TE_{ij}} + \sum_{s=1}^{3} \gamma_{TOT}^s (\tau_{ij}^{OT} \times Q_{ij}^s) + \sum_{s=1}^{3} \gamma_{TOL}^s (\tau_{ij}^{OL} \times Q_{ij}^s) + \\
3 \sum_{s=1}^{3} \gamma_{TIT}^s (\tau_{ij}^{IT} \times Q_{ij}^s) + 3 \sum_{s=1}^{3} \gamma_{TIL}^s (\tau_{ij}^{IL} \times Q_{ij}^s) + \delta_i T_i + \mu_i + \varepsilon_{ij}
\] (3.7)

Which are just equations (3.2)-(3.4) adjusted to obtain results per firm size. Now, s indexes the three different firm sizes, and \(Q_{ij}^s\) is an indicator variable equal to one when firm \(i\) belongs to firm size \(s\). The estimates for equations (3.2) - (3.4) are presented in Tables 3.7 - 3.9 for each firm size. Column 1 of table 3.7 presents the results of equation (3.5) for large firms. The positive coefficient on both output tariffs and output license coverage can once again reflect the profit motive and/or the substitution effect. The negative coefficients on both input tariffs and the input license coverage measure reflect the profit motive for increasing royalty payments.

For large firms, three trade measures are significant: output tariffs and input and output licenses. The results from column 1 show that a 10 percentage point decrease in output tariffs and the output license coverage measure results in a 11.9 percent and 4.7 percent decrease in average royalty payments made per employee, while a 10 percentage point decrease in input tariffs and the input license coverage measure result in a 7.1 percent and a 9.5 percent increase. Columns 2 and 3 of Table 3.7 show that additionally controlling for
imports of capital goods and profit does not change the estimated effects of trade protection on royalty payments. The estimated coefficient for imported capital, while insignificant, has the correct positive sign; indicating, that large firms are motivated by profits when they purchase technology. Both interaction terms, the measure of profits, and the quality measure of the workforce are insignificant.
Table 3.7 Results: Large Firms

<table>
<thead>
<tr>
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<th>Model (1)</th>
<th>Model (2)</th>
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<td></td>
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<td>(0.018)</td>
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<td>0.060*</td>
<td>0.060*</td>
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<td>(0.031)</td>
<td>(0.031)</td>
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<td>0.219***</td>
<td>0.217***</td>
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<td>(0.003)</td>
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Notes: Robust standard errors in parentheses. A set of year dummies are included in all specifications.

*** Significant at .01 percent.
** Significant at .05 percent.
* Significant at .10 percent.
Table 3.8 Results: Medium Firms

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Notes: Robust standard errors in parentheses. A set of year dummies are included in all specifications.

*** Significant at 5 percent.
** Significant at 15 percent.
* Significant at 20 percent.
## Table 3.9 Results: Small Firms

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</tr>
<tr>
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<td>(0.030)</td>
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<td>0.050*</td>
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<td>(0.032)</td>
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<td>-0.090</td>
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<td>(0.151)</td>
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<td>-0.002**</td>
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<td>(0.001)</td>
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</tr>
<tr>
<td>ImpIntT</td>
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<td>0.0001*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
<td></td>
</tr>
<tr>
<td>ImpIntL</td>
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<td>-0.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
<td></td>
</tr>
<tr>
<td>ProfitM</td>
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</tr>
<tr>
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<td>R-squared</td>
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<tr>
<td>F Test (p-value)</td>
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</table>

Notes: Robust standard errors in parentheses. A set of year dummies are included in all specifications.
*** Significant at 5 percent.
** Significant at 10 percent.
Similar to the regression with all the firms, the coefficients on non-wage benefits, sales commissions, and advertising costs are positive and significant. Once again, increasing advertising costs has the biggest impact on royalty payments. Increasing advertising costs by one million MXP increases royalty payments by 218,000 MXP. The same increase in sales commissions and non-wage benefits leads to a 60,000 and 34,000 MXP increase, respectively. The only coefficient that does change is the coefficient on non-wage benefits. When imported capital is added, the point estimate for this control variable decreases slightly and is significant at 10 percent. When profits are added, the point estimate for non-wage benefits decreases even more and is significant at 15 percent.

The effect of the reduction in tariffs on the medium sized firms is less precisely estimated. None of the trade variables are significant. Since medium sized firms spend more on average royalty payments per employee than large and small firms, one plausible explanation for the insignificant coefficients on the trade variables is that medium sized firms are motivated by profits and competition only when they decide to purchase technology. It can be that medium sized firms believe that the only way that they can compete with larger firms is by purchasing technology, and this decision has nothing to do with trade policy. The conjecture that medium sized firms are motivated by competition is supported by the significant and positive coefficient on advertising costs. A one million MXP increase in advertising leads to a 230,000 MXP increase in royalty payments; higher than the increase experienced by large firms.

This increase in royalty payments is consistent when imports of capital goods is controlled for and decreases slightly when profits are controlled for. Columns 1-3 in table 3.8 show the importance of non-wage benefits on royalty payments and further supports the competition hypothesis for why medium sized firms purchase technology. Firms that
are willing to pay non-wage benefits to their employees are not only trying to entice better workers, but they are also trying to encourage their current employees to be productive. Increasing non-wage benefits by one million MXP increases royalty payments by 687,000 MXP. Controlling for the imports of capital goods lowers the increase in royalty payments to 685,000 MXP. Controlling for profits changes the significance level and lowers the increase in royalty payments to 514,000 MXP. The point estimate for profits is positive and significant, but has a minor impact on royalty payments. A one million MXP increase in profit increases royalty payments by 20,000 MXP.

For small firms, two trade measures are significant: input tariffs and input licenses. The results from column 1 of Table 3.9 show that a 10 percentage point decrease in input tariffs results in a 39.2 percent decrease in average royalty payments per employee. A 10 percentage point decrease in the input license coverage measure results in a 9.8 percent increase in average royalty payments per employee. Columns 2 and 3 of Table 3.9 show that additionally controlling for imports of capital goods and profit does not change the estimated effects of trade protection on royalty payments. The estimated coefficients for the trade measure indicate that small firms are motivated more by the substitution effect when purchasing technology than the profit motive. The estimated coefficient on imported capital is negative and significant; substantiating the fact that small firms are motivated by the substitution effect when they purchase technology. The caveat is that the estimated impact on royalty payments is quite small; a million MXP increase in expenditure on imported capital goods causes a 20,000 MXP decrease in royalty payments. Both interaction terms have the correct sign, but only the interaction of imported capital goods with import tariffs is significant. Once again, the caveat is that the estimated coefficient for the interaction term is quite small.
The estimated coefficient for non-wage benefits is positive and significant. Increasing non-wage benefits by 1 million MXP increases royalty payments by 101,000 MXP. Controlling for imports of capital goods and profits does not drastically change the point estimate for non-wage benefits and its significance. The estimated coefficient for profits is negative and significant; albeit, with a small estimated impact on royalty payments. The reason for the negative coefficient for profits is the fact that small firms tend to purchase significantly more technology when input tariffs increase. High input tariffs decreases firm profitability which is the rationale behind why the point estimate for profits is negative i.e. a decrease in profits increases royalty payments.

3.7 Conclusion

Much research has been conducted concerning trade liberalization and growth. Sachs and Warner (1995) studied data on developing countries and concluded that those countries that had liberalized trade experienced higher growth rates than those countries that had instead opted to erect barriers to free trade. They also concluded that the income of countries with liberalized trade was higher than the income of countries that hindered free trade. Ben-David and Loewy (1998) also study the effect of trade liberalization on output and growth rates. Their research shows that liberalized trade leads to higher growth rates in developing countries.

The effect of trade liberalization on productivity has been studied extensively as well. Coe, Helpman, and Hoffmaister (2008) research the effect of trade on technology diffusion and TFP. The authors find that the stock of foreign R&D capital, the stock of domestic R&D capital and domestic TFP are cointegrated. They conclude that there exists a significant
amount of technology transfer from more advanced countries to less developed countries. Coe, Helpman and Hoffmaister also find that technology diffusion is highest when countries have policies in place that facilitate free trade, and they find that technology diffusion has a positive impact on TFP. Ferreira and Rossi (2003) use industry level data from Brazil to investigate the effect that trade liberalization has on TFP. The authors find that reducing trade barriers not only increases the growth rate of TFP, but it also increases labor productivity.

Less research has been conducted concerning the effect that trade liberalization has on technology adoption by firms in developing countries. To date, Bustos (2011), Teshima (2010), and Gorodnichenko et al. (2010) conduct research that focus specifically on investigating the effect of trade liberalization on technology adoption. To the best of the author’s knowledge, this is the first study to estimate the impact that trade liberalization has on technology diffusion in a developing country using both input and output tariffs as well as measures for input and output license coverage. The estimation strategy that was used allows me to control for plant-specific, time-invariant unobservables. Not including establishment-specific, time-invariant unobservables can bias the estimated results. The standard errors were also adjusted for HK and serial correlation; making the statistical inference precise. The estimated coefficients for the trade measures remained constant even when controlling for imported capital goods and profits.

In the case of all firms, output tariffs and the output license coverage measure positively affect royalty payments. A 10 percentage point decrease in output tariffs decreases royalty payments per employee by 15.8 percent. A 10 percentage point decrease in the output license coverage measure decreases royalty payments per employee by 6.3 percent. The estimated results indicate that firms are probably substituting away from purchasing patents to directly importing capital goods if output tariffs and the output license coverage measure
are lowered.

In order to empirically test to see if there is heterogeneity in the impact of Mexico’s trade liberalization on firm-level investment, I divide the firms into the following three groups based on the total number of employees each firm had in 1984: large, medium, and small. I find that there is significant heterogeneity across firm size. For large firms, three trade measures are significant: output tariffs and input and output licenses. A 10 percentage point decrease in output tariffs and the output license coverage measure results in a 11.9 percent and 4.7 percent decrease in average royalty payments made per employee, while a 10 percentage point decrease in input tariffs and the input license coverage measure result in a 7.1 percent and a 9.5 percent increase. The estimated results support the hypothesis that large firms are motivated by profits when they purchase technology.

The effect of the reduction in tariffs on medium sized firms is less precisely estimated. None of the trade variables are significant. Since medium sized firms spend more on average royalty payments per employee than large and small firms, one plausible explanation for the insignificant coefficients on the trade variables is that medium sized firms are motivated by profits and competition only when they decide to purchase technology. It can be that medium sized firms believe that the only way that they can compete with larger firms is by purchasing technology, and this decision has nothing to do with trade policy.

For small firms, two trade measures are significant: input tariffs and input licenses. A 10 percentage point decrease in input tariffs results in a 39.2 percent increase in average royalty payments per employee. A 10 percentage point decrease in the input license coverage measure results in a 9.8 percent increase in average royalty payments per employee.

The results indicate that it is important to study the effect of trade liberalization on royalty payments using both input and output tariffs and license coverage measures. The results
also show that the effect of trade liberalization on royalty payments differs from the typical results that trade liberalization has on technology adoption. A conclusion that is missed if royalty payments are included in a broad measure of technology adoption that includes both product and process R&D that is conducted within the firm. The results suggest that trade liberalization decreases royalty payments because firms switch from purchasing patents to directly purchasing the cheaper, technologically advanced capital goods. The main conclusion my research makes is that trade liberalization decreases the importance of patents and licenses as a channel of technology diffusion.

The main results of my model stem from the fact that Mexico underwent a drastic transition from having a closed, highly regulated economy, to having a very open economy that fostered free trade. The dataset I used reflects the immediate effect of technology diffusion on royalty payments. A possible idea for future research would be to study if patent and license purchases eventually begin to increase again years after trade liberalization has taken place. With the new data that is being collected in developing countries with respect to R&D and royalty payments, it would also be interesting to investigate whether in-house R&D and patent purchases are substitutes or complements.


Appendices
Appendix A

Appendix to Chapter 1

A.1 Overview of the Model

A.1.1 Calculating the Optimal Aggregate Demand of Intermediate Goods

Using the fact that \( C_i \equiv X_i = L \cdot C_i \), at each time \( t \), individuals maximize

\[
C = \left[ \int_0^{N_B} C_i^{(\eta-1)\eta} \, d_i \right]^{\eta/(\eta-1)}
\]

s.t. \( E = \int_0^{N_B} P_i C_i d_i \)

The Lagrangian for the consumer’s maximization problem is

\[
L = \left[ \int_0^{N_B} C_i^{(\eta-1)\eta} \, d_i \right]^{\eta/(\eta-1)} + \lambda \left[ E - \int_0^{N_B} P_i C_i d_i \right]
\]

Setting \( \frac{\partial L}{\partial C_i} = 0 \) yields

\[
\left[ \int_0^{N_B} C_i^{(\eta-1)\eta} \, d_i \right]^{1/(\eta-1)} C_i^{-\frac{1}{\eta}} = \lambda P_i
\]

Solving for \( C_i \) yields

\[
C_i = \lambda^{-\eta} P_i^{1 - \eta} \left[ \int_0^{N_B} C_i^{(\eta-1)\eta} \, d_i \right]^{\eta/(\eta-1)}
\]  

(A.1)

The relationship between \( C \) and \( E \) is that
\[ E = \int_0^N P_i C_i d_i \]

Using this relationship and substituting for \( C_i \) using (A.1) yields

\[ \lambda^{-\eta} = \frac{E}{\int_0^{NB} P_i^{-\eta} \left[ \int_0^{NB} C_i^{(n-1)/\eta} d_i \right]^{\eta/(\eta-1)}} \tag{A.2} \]

Substituting for \( \lambda \) in equation (A.1) using (A.2) yields

\[ C_i = E \left[ \frac{P_i^{-\eta}}{\int_0^{NB} P_j^{-\eta} d_j} \right] \]

where \( C_i \) represents the optimal input of good \( i \) into the production of the final good \( C \). The optimal aggregate demand of \( C_i \equiv X_i = L \cdot C_i \) is

\[ X_i = LE \left[ \frac{P_i^{-\eta}}{\int_0^{NB} P_j^{-\eta} d_j} \right] \tag{A.3} \]

### A.1.2 Calculating the Cost of Entry

The amount of labor required to produce one unit of \( \dot{M} \) is \( \frac{L_M}{M} = \frac{1}{\alpha NB} \). This means that the cost of one unit of \( \dot{M} \) is \( \frac{w}{\alpha NB} \). The standard free-entry condition for the sector of the economy that conducts R&D that is aimed at imitating goods is \( P_{Mi} = \frac{w}{\alpha NB} \). In order for firms to be willing to conduct R&D that is aimed at imitating goods, then it must also hold that \( v_{Mi} = \frac{w}{\alpha NB} \).

This means that the cost of a patent for an imitated good equals its value and its price. The amount of labor required to produce one unit of \( \dot{N} \) is \( \frac{L_N}{N} = \frac{1}{\beta NB} \). This means that the cost of one unit of \( \dot{N} \) is \( \frac{w}{\beta NB} \). The standard free-entry condition for the sector of the economy that conducts R&D that is aimed at imitating goods is \( P_{Ni} = \frac{w}{\beta NB} \). In order for firms to be willing
to conduct R&D that is aimed at imitating goods, then it must also hold that \( v_{Ni} = \frac{w}{\beta N_B} \).

This means that the cost of a patent for an imitated good equals its value and its price.

### A.1.3 Calculating the Optimal Price that Maximizes Profit

Per firm profit equals \( \pi_i = P_i X_i - w X_i \). Maximizing profit w.r.t. price yields

\[
\frac{LE(1-\eta) P_i^{-\eta} j_i^{-\eta} d_j}{\int_0^1 P_j^{-\eta} d_j} = \frac{\eta LEP_i^{-\eta} - \dot{w}}{\int_0^1 P_j^{-\eta} d_j}
\]

Rearranging terms and solving for price, yields that the associated pricing strategy is the mark-up rule \( P_i X = \frac{w \eta}{(\eta-1)} \).

### A.1.4 The Rate of Return to Imitation and Innovation and the Investment Decision

The standard asset pricing equation for the rate of return to R&D is \( r = \frac{\pi_i}{\dot{v}_i} + \frac{\ddot{v}_i}{\dot{v}_i} \). Using the fact that \( \pi_i = P_i X_i - w X_i \) and \( P_i X = \frac{w \eta}{(\eta-1)} \), profit reduces to \( \pi_i = \frac{LE}{\eta N_B} \). Substituting for \( v_{Mi} = \frac{w}{\alpha N_B} \) and \( v_{Ni} = \frac{w}{\beta N_B} \), the rate of return to imitation and innovation respectively is

\[
r_M = \frac{\alpha L E}{\eta w} + \frac{w}{w} \frac{N_B}{N_B} = \rho \quad \text{(A.4)}
\]

\[
r_N = \frac{\beta L E}{\eta w} + \frac{w}{w} \frac{N_B - \dot{\beta}}{\beta N_B} = \rho \quad \text{(A.5)}
\]

As can be seen from (A.4) and (A.5), as long as \( \beta < \alpha \), the rate of return to R&D that is aimed at imitating goods is higher than the rate of return that is aimed at inventing new goods. This means that entrepreneurs choose to enter the market as imitators in the steady
state. If $\alpha = \beta$ asymptotically, $\frac{\dot{\beta}}{\beta} = 0$, so the rate of return to both types of R&D are equal. This means that firms will invest in both types of R&D in the steady state. Firms choose to enter the market as inventors once $\beta = \alpha + \frac{\delta nw}{LE}$. $\delta$ is the value of $\frac{\dot{\beta}}{\beta}$ that occurs right before firms decide to shut down investment in imitation. This means that $\beta > \alpha$ for innovation to take place in the steady state.

### A.2 General Equilibrium Results

#### A.2.1 Steady State Growth Rates

Solving for the steady state for each regime follows the method of G-H. In regime 1, $\dot{N} = 0$, so $N_B = M$ and $\frac{N_B}{N_B} = \frac{M}{M}$. Using the resource constraint $L = L_X + L_M + L_N = \frac{LE}{P_X} + \frac{M}{\alpha N_B} + \frac{N}{\beta N_B}$ to solve for $\frac{M}{N_B}$ yields

$$\frac{N_B}{N_B} = \alpha L - \frac{\alpha LE}{P_X}$$

(A.7)

Using the fact that $P_{iX} = \frac{w\eta}{(\eta - 1)}$, and $v_{Mi} = \frac{w}{\alpha N_B}$ and plugging both into (A.7) yields

$$\frac{N_B}{N_B} = \alpha L - \frac{LE(\eta - 1)}{\eta v N_B}$$

Following the method of G-H, in order to simplify the analysis, I define the rate at which new product varieties are being introduced into the economy as $\frac{N_B}{N_B} \equiv g_M$, and I define the inverse of the economy’s aggregate equity value as $V \equiv \frac{1}{v N_B}$. I then rewrite (A.7) as

$$g_M = \alpha L - \frac{LE(\eta - 1)V}{\eta}$$

(A.8)
Using the definitions of $V$ and $g_M$, it is apparent that $\dot{V} = -\frac{v}{V} \dot{V} - g_M$ and $\dot{v} = -g_M - \frac{V}{V}$. Using the fact that $r = \rho$, I calculate

$$\dot{v} = \rho - \frac{LE}{\eta \nu N_B}$$

This means that

$$-\frac{\dot{V}}{V} - g_M = \rho - \frac{LE}{\eta \nu N_B}, \text{ and } \frac{\dot{V}}{V} = \frac{LE}{\eta \nu N_B} - \rho - g_M$$

Substituting for $V$, this just becomes $\dot{V} = \frac{LEV}{\eta} - \rho - g_M$. In the steady state $\dot{V} = 0$, so that $\frac{LEV}{\eta} - \rho = g_M$, and $V = \frac{\eta g_M + \eta \rho}{LE}$. I then plug $V = \frac{\eta g_M + \eta \rho}{LE}$ into (A.8). This yields

$$g_M = \alpha L - \frac{LE(\eta - 1)(\eta g_M + \eta \rho)}{\eta LE} = \alpha L - (\eta - 1)g_M - (\eta - 1)\rho$$

A bit of algebra yields

$$g_M = \frac{\alpha L}{\eta} - \frac{(\eta - 1)\rho}{\eta} \quad (A.9)$$

Which is the growth rate for regime 1 and regime 3. Solving for the growth rate of regime 2 follows the same logic and yields

$$g_N = \frac{\beta L}{\eta} - \frac{(\eta - 1)\rho}{\eta} \quad (A.10)$$
Appendix B

Appendix to Chapter 2

B.1 Pareto Optimality

B.1.1 Optimal Output

The consumption index is re-defined based on the static optimization problem that is faced by the social planner. Following the method of G-H, I redefine the static allocation problem that is faced by the social planner as maximizing

\[
C = \left[ \int_0^{N_B} c_i^{(\eta-1)/\eta} \, d_i \right]^{\eta/(\eta-1)} \text{ s.t. } \int_0^{N_B} X_i d_i \leq X.
\]

The Lagrangian for the social planner’s maximization problem is

\[
L = \left[ \int_0^{N_B} x_i^{(\eta-1)/\eta} \, d_i \right]^{\eta/(\eta-1)} + \lambda \left[ X - \int_0^{N_B} X_i d_i \right]
\]

and the Kuhn-Tucker conditions are
\[
\frac{\partial L}{\partial X_i} = \left[ \int_0^{N_B} X_i^{(\eta-1)/\eta} \, dt_i \right]^{1/(\eta-1)} X_i^{-\frac{1}{\eta}} - \lambda N_B \leq 0
\]

\[X_i \geq 0\]

\[X_i \left( \int_0^{N_B} X_i^{(\eta-1)/\eta} \, dt_i \right)^{1/(\eta-1)} X_i^{-\frac{1}{\eta}} - \lambda N_B \right) = 0\]

\[
\frac{\partial L}{\partial \lambda} = X - \int_0^{N_B} X_i \, dt_i \leq 0
\]

\[\lambda \geq 0\]

\[\lambda (X - \int_0^{N_B} X_i \, dt_i) = 0\]

I then test the Kuhn-Tucker conditions methodically. If \( \lambda = 0 \), then

\[
\left[ \int_0^{N_B} X_i^{(\eta-1)/\eta} \, dt_i \right]^{1/(\eta-1)} X_i^{-\frac{1}{\eta}} = 0
\]

which is not possible. This means that \( X - \int_0^{N_B} X_i \, dt_i = 0 \) and \( \lambda > 0 \). \( X_i \) also can not equal zero, so

\[
\left[ \int_0^{N_B} X_i^{(\eta-1)/\eta} \, dt_i \right]^{1/(\eta-1)} X_i^{-\frac{1}{\eta}} - \lambda N_B = 0
\]

I then proceed to solve for \( X_i \). This means that \( X_i^{-\frac{1}{\eta}} = \frac{\lambda N}{\left[ \int_0^{N_B} X_i^{(\eta-1)/\eta} \, dt_i \right]} \) and

\[
X_i = \lambda^{-\eta} N^{-\eta} \left[ \int_0^{N_B} X_i^{(\eta-1)/\eta} \, dt_i \right]^{\eta/(\eta-1)} \quad \text{(B.1)}
\]

I then substitute (B.1) into \( X = \int_0^{N_B} X_i \, dt_i \) so that

137
\[ X = \int_0^{NB} \lambda^{-\frac{1}{\eta}} N^{-\frac{1}{\eta}} \left[ \int_0^{NB} X_i^{(\eta - 1)/\eta} d_i \right]^{\eta/(\eta - 1)} d \]

A bit of algebra yields that

\[ \lambda^{-\eta} = \frac{X}{N^{(1-\eta)} \left[ \int_0^{NB} X_i^{(\eta - 1)/\eta} d_i \right]^{\eta/(\eta - 1)}} \tag{B.2} \]

Substituting (B.2) into (B.1) yields that

\[ X_i = \frac{X N^{-\eta} \left[ \int_0^{NB} X_i^{(\eta - 1)/\eta} d_i \right]^{\eta/(\eta - 1)}}{N^{(1-\eta)} \left[ \int_0^{NB} X_i^{(\eta - 1)/\eta} d_i \right]^{\eta/(\eta - 1)}} = \frac{X}{N} \tag{B.3} \]

This is the optimal allocation for the division of labor in manufacturing for the social planner. This is also the division of labor in manufacturing that the decentralized equilibrium achieves. The only difference is that the optimal aggregate output \( X \) is less than the decentralized equilibrium output.

## B.2 Government Intervention

### B.2.1 Subsidies to R&D

One of the ways that the government can intervene in the economy in order to achieve the Pareto optimal result in a free market economy is by using a lump-sum tax to finance a
subsidy to R&D. If the government subsidizes R&D by paying a portion $\phi_R$ of all research expenses, entrepreneurs have an incentive to invent more products; thereby, increasing the growth rate of varieties. With a subsidy to R&D

$$V_{Mi} = \frac{w(1-\phi_R)}{\alpha N_B}$$
$$v_i = \frac{(1-\phi_R)w}{\beta N_B}$$

for entry by imitation and innovation respectively. The no-arbitrage condition is $g = \rho - \frac{\pi_i}{v_i}$. Using the fact that $r = \rho$, $\frac{v_i}{v_i} = g_{NB}$, $\pi_i = \frac{\alpha LE}{(1-\phi_R)\eta w}$, $\pi_i = \frac{\beta LE}{(1-\phi_R)\eta w}$, $X = \frac{LE(\eta-1)}{\eta w}$, to obtain

$g_{NB} = \rho - \frac{\alpha LE}{\eta(1-\phi_R)w}$

for imitation and innovation respectively. Multiplying both equations by $\frac{(\eta-1)}{(\eta-1)}$ yields

$$\frac{\alpha X}{(1-\phi_R)(\eta-1)} = g_{NB} + \rho \quad \text{(B.4)}$$
$$\frac{\beta X}{(1-\phi_R)(\eta-1)} = g_{NB} + \rho \quad \text{(B.5)}$$

for the no arbitrage conditions for imitation and innovation with government intervention.

The no arbitrage condition for the decentralized equilibrium is

$$\frac{\alpha X}{\eta-1} = g_{NB} + \rho$$
$$\frac{\beta X}{\eta-1} = g_{NB} + \rho$$

The subsidy causes the NA curve to rotate clockwise to the right, but leaves the RC curve unchanged.
B.2.2 Subsidies to Manufacturing

Besides subsidizing R&D, the government can also subsidize manufacturing with a lump-sum tax. It is assumed that $\phi_X$ is the ad valorem rate of the subsidy to manufacturing. With this policy, manufacturers receive $P_X(1 + \phi_X)$ for each unit of output that is sold, but consumers pay $P_X = \frac{w \eta}{(\eta - 1)(1 + \phi_X)}$ for each unit of output. The free entry condition does not change, but now profits for the firm are

$$\pi_i = [P_X(1 + \phi_X) - w] X_i$$

$$\pi_i = \frac{\eta(1 + \phi_X)LE - (\eta - 1)LE(1 + \phi_X)}{N \eta}$$

$$\pi_i = \frac{(1 + \phi_X)LE}{N \eta}$$

and

$$X = \frac{LE(\eta - 1)(1 + \phi_X)}{\eta w}$$

The no arbitrage condition is

$$\frac{\alpha LE(1 + \phi_X)}{w \eta} = g_{N_B} + \rho$$

$$\frac{\beta LE(1 + \phi_X)}{w \eta} = g_{N_B} + \rho$$

for imitation and innovation respectively. Multiplying both equations by $\frac{(\eta - 1)}{(\eta - 1)}$ yields

$$\frac{\alpha X}{(\eta - 1)} = g_{N_B} + \rho \quad \text{(B.6)}$$

$$\frac{\beta X}{(\eta - 1)} = g_{N_B} + \rho \quad \text{(B.7)}$$

and is exactly equal to what is obtained with the decentralized equilibrium. The subsidy to manufacturing has not provided any incentive for entrepreneurs to increase the growth rate of either imitated or innovated product varieties, so the decentralized equilibrium growth
rate remains constant even after the subsidy to output. The reason why the growth rate is constant is because the government’s subsidy not only augments manufacturing, but it also augments research at the same time. Because of this, entrepreneurs, who need researchers, and established firms that need labor for manufacturing compete for workers and bid up the wage rate. A subsidy to manufacturing is ineffective because wages increase; therefore, it ends up not promoting R&D nor manufacturing.

B.2.3 Optimal Subsidies

Using the fact that \( X = L - \frac{g_{NB}}{\alpha} \) and \( X = L - \frac{g_{NB}}{\rho} \)

\[
g_{NB} + \rho = \frac{\alpha(L - \frac{g_{NB}}{\alpha})}{(\eta - 1)(1 - \phi_R)}
\]

such that

\[
\phi_R = 1 - \frac{\alpha(L - \frac{g_{NB}}{\rho})}{(\eta - 1)(g_{NB} + \rho)}
\]

I then substitute for \( g_{NB} \) using the Pareto optimal growth rate \( g_{NB}^* = L\alpha - (\eta - 1)\rho \) and

\[
\phi_R = 1 - \frac{\rho}{L\alpha - (\eta - 1)\rho + \rho}
\]

\[
\phi_R = 1 - \frac{\rho}{g_{NB}^* + \rho}
\]

\[
\phi_R^* = \frac{g_{NB}^*}{g_{NB}^* + \rho}
\]  \hspace{1cm} (B.8)

Which is the optimal subsidy that will increase the decentralized equilibrium growth rate so
that it is equal to the social planner’s growth rate in each regime. This subsidy also decreases the output for the decentralized equilibrium so that it is equal to the Pareto optimal output.

**B.2.4 Optimal Value of Worker Efficiency**

The assumption is made that the government intervenes in the economy with a lump-sum tax and education and health adjust immediately, so the efficiency of labor adjusts immediately without diffusion lags as well. With government intervention, workers become more efficient at R&D. This changes the slope of the RC line and shifts it out. The NA curve also rotates clockwise to the right. The optimal values for $\alpha$ and $\beta$ are calculated by setting

\[
L\alpha - \eta \rho + \rho = \frac{\alpha L}{\eta} - \frac{\eta \rho}{\eta} + \frac{\rho}{\eta}
\]
\[
L\beta - \eta \rho + \rho = \frac{\beta L}{\eta} - \frac{\eta \rho}{\eta} + \frac{\rho}{\eta}
\]

Solving for $\alpha$ and $\beta$ yield

\[
\alpha^* = \frac{\rho(1 - 2\eta + \eta^2)}{L(\eta - 1)} \quad \text{(B.9)}
\]
\[
\beta^* = \frac{\rho(1 - 2\eta + \eta^2)}{L(\eta - 1)} \quad \text{(B.10)}
\]

Which are the optimal values for worker efficiency. These are the values that are needed in order to bring the decentralized growth rate to the social planner’s growth rate.