Essays on Multi-Product Firms and International Trade

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Für meine Eltern.

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Preface

Traditional trade theory does not pay much attention to the behavior of firms in global markets. However, the emergence of a wide range of micro level datasets has changed the way economists conduct research in international trade. While in traditional trade models, the emphasis is placed on industries and countries, the majority of recent research focuses rather on firms and products. In the mid-1990s, a series of empirical papers based on a first wave of microdata demonstrated that firms are heterogenous within industries. Beginning with Bernard and Jensen (1995, 1999), this literature documents that even within narrowly defined industries, some firms are much larger and make higher profits than others because they are more productive. Furthermore, it is documented that these most productive firms drive international trade flows. The fact that exporting firms are different and more productive than firms that operate only domestically is widely documented and has been proven to be robust to many control variables (see Bernard et al. (2007) and Bernard et al. (2012)).[1] According to this, the participation in exporting is not random but crucially depends on firm characteristics.

This thesis is inspired by more recent micro level data which shows large differences in the characteristics of firms even within the fraction of firms that participate in export markets. One of the striking features of this data is that the majority of international trade is concentrated on a small number of very large firms. For the year 2000, Bernard et al. (2009) report that the top one percent of trading firms account for 81 percent of U.S. trade. Trade economists explain this concentration

[1] Next to the reported differences in productivity, Bernard et al. (2007) document a number of further dimensions in which exporters differ from nonexporters. Exporters are significantly larger in terms of employment and shipments. Furthermore, exporters pay higher wages and are relatively more capital- and skill-intensive than nonexporters.

by the fact that large firms are engaged in multi-product trade. Empirical observations document that firms producing multiple products play a dominant role in both domestic and international businesses and in many cases their dominance has increased with globalization. Detailed micro level data reveals interesting characteristics of exporting firms as it links firms to the number of products they produce and to their foreign export destinations.[2] For US exporters, Bernard et al. (2007) show that about 26 percent of firms export five or more products, and that these firms account for about 98 percent of the total value of exports. A similar pattern is reported by Mayer and Ottaviano (2007) for French exporters. In their dataset, roughly 34 percent of French firms export more than five products and these firms account for 91 percent of total exports.[3] These findings highlight the dominance of multi-product firms (MPFs) in global markets and motivated a fast growing literature on MPFs and international trade. This avenue of research and its promising developments are the starting point of my thesis, which aims to provide theoretical and empirical contributions to a better understanding of how firms behave in global markets. Crucially, all new insights gained from the analysis in the different chapters are only enabled due to the fact that the underlying frameworks allow for MPFs.

On the theoretical side, MPFs have received attention for some years in the industrial organization literature (e.g. Brander and Eaton (1984), Shaked and Sutton (1990), Eaton and Schmidt (1994), Johnson and Myatt (2003), and Allanson and Montagna (2005)). Existing theoretical research on MPFs in international trade is concerned mainly with the product market side of the economy, where the main research question is how MPFs absorb trade shocks. This fast growing literature can be divided roughly into two strands regarding the assumptions made about the underlying market structure. In the *first* strand of models, research is concentrated on monopolistically competitive MPFs (see Bernard et al. (2011), Arkolakis and Muendler (2012), Nocke and Yeaple (2013), and Mayer et al. (2014)). Assuming a continuum of firms implies that firms are implicitly negligible to the market and, therefore, demand linkages among products within the firm are excluded. These

[2] See also World Trade Organisation (2008).

[3] The dominance of multi-product firms in export markets is not only true for developed countries. For Peru, Martinicus and Carballo (2008) report that the average exporter sells 7.5 products. For other country studies, see Iacovone and Javorcik (2008) for Mexico, and Goldberg et al. (2010) for India.

linkages are highlighted in the *second* strand of the literature, where the assumption of monopolistic competition is dropped and firms are considered to attain a finite mass in an oligopolistic market structure. In models such as Ju (2003), Eckel and Neary (2010), and Eckel et al. (2011), firms are large relative to the market and hence internalize demand linkages within their product portfolio, the so called "cannibalization" effect.[4] In this context, cannibalization means that widening the product range by one additional variety exerts a negative externality on the products initially offered by the firm and reduces their respective market shares. This effect plays an important role in my thesis which is therefore more related to the second strand of the literature. Indeed, I will show that allowing for firms which internalize cannibalization effects across their products will provide novel and interesting insights into the adjustment processes of firms to globalization.

A commonality in many papers on MPFs and international trade is the emphasis of the product range as a new margin of adjustment to globalization. Economists have analyzed the effects of globalization on this new margin which Eckel and Neary (2010) refer to as responses at the "intra-firm extensive margin". Indeed, as several recent papers document, this margin of adjustment is of great importance. Broda and Weinstein (2010) find that 82 percent of the new product creation occurs within existing firms and thus only 18 percent of the value of overall consumption goes back to new products of entering firms. Bernard et al. (2010) report a somewhat lower figure of about half of the US output of new products stemming from within-firm product expansion. Furthermore, they document changing product ranges for more than 50 percent of US firms within five years. Since the seminal work of Krugman (1979), product variety has played an important role in many trade models. Throughout this thesis, the question of how globalization affects the product range of MPFs will be discussed in great detail. From a welfare perspective, this question is of central importance because of the great contribution of varieties from within-firm product expansion to the overall number of available varieties in an economy. Therefore, I argue that analyzing the product range of MPFs and understanding the determinants, which may have an influence on it, is a crucial aspect to have in mind when studying the variety gains from international trade.

[4] Two papers that assume monopolistic competition but yet feature the cannibalization effect are Feenstra and Ma (2008) and Dhingra (2013).

Among heterogenous firms, globalization creates both winners and losers: On the one hand, markets expand but, on the other hand, the degree of competition intensifies. The literature has shown that while for low-performing firms the competition effect dominates, better-performing firms benefit from better access to foreign markets (see e.g., Melitz (2003) and Bernard et al. (2003)).[5] I concentrate my analysis on large MPFs, for whom a more integrated world market brings forth a number of new challenges and opportunities, in addition to better prospects for exporting. In particular, I focus on two important issues: (1) *offshoring* and (2) the positive impacts of larger markets on *innovation*. Both issues have obtained a lot of attention in the existing international trade literature, however, there are only few insights on these topics in the context of MPFs. Therefore, my dissertation aims to establish a connection between the literature on offshoring and innovation, on the one hand, and recent achievements on MPFs, on the other hand. By doing so, I focus on issues that cannot be explained in models based on single-product firms.

This thesis consists of three main chapters, all contributing to the literature on MPFs and international trade. In these chapters, I show, for example, how the opportunity to relocate entire production lines affects the product range of an MPF. This type of international expansion is labeled as "multi-product offshoring" and is shown to bring forth labor market implications that are crucially different from models on offshoring with single-product firms (Chapter 1). In Chapters 2 and 3, I analyze the impact of larger markets on innovation, where the modelling of MPFs allows me to differentiate between different types of innovation. In Chapter 2, the focus is on a trade-off between process and product innovation, which is created by cost and demand linkages. These linkages are specific to MPFs and can both be related to the degree of product differentiation in an industry. It is theoretically shown and later on empirically confirmed that firms in more differentiated sectors will do more product innovation, whereas firms in more homogeneous sectors will invest more in better processes. Chapter 3 takes up again the two types of investments from Chapter 2 and adds investments in the degree of product differentiation as a third strategic variable an MPF may choose. The focus of Chapter 3 is to show how unbundling the different types of innovation leads to new insights into the welfare gains from trade liberalization. In the following, I provide a brief overview of the

[5] For recent surveys, see also Melitz and Trefler (2012) and Melitz and Redding (2013).

lines of argumentation in each chapter and highlight the main results as well as the contributions to the literature.

In Chapter 1, which is joint work with Carsten Eckel, we incorporate offshoring of labor-intensive goods in a multi-product framework. Although the internationalization of production has been discussed extensively in the literature, there is not yet a framework to study the relocation of whole varieties within the boundaries of a firm. We refer to this phenomenon as "multi-product offshoring" and emphasize that our analysis brings forth new insights into the labor market outcomes of offshoring. Prior academic research on international production has identified two main channels through which offshoring affects domestic labor demand. Firstly, there is a relocation effect from the displacement of tasks that formerly were carried out domestically. Secondly, there are efficiency gains from vertical specialization that benefit domestic workers and increase domestic demand for labor (see Eckel (2003), Grossman and Rossi-Hansberg (2008), Rodriguez-Clare (2010), and Egger et al. (2013)). We argue that the efficiency effect of offshoring can only occur if the production of a single good is linked sequentially in two or more countries. Moreover, at least part of the production stages have to remain in the home country so that domestic employment can benefit from the higher productivity. If, however, the complete production line is relocated, the latter effect vanishes. On top of that, multi-product offshoring not only prevents the efficiency effect but causes a cannibalization effect of offshoring which has not been discussed in the literature, yet.

In our multi-product framework, we investigate how improvements in the opportunities for offshoring affect the geographic organization and the product range of an MPF. A firm which produces a range of products can decide for each product where it is produced most efficiently: In the home country or in a low-wage offshore destination. Therefore, it is the labor intensity of each product that determines its optimal production location. As a main result in partial equilibrium, we show that lower offshoring costs will lead to a relocation of labor-intensive products and to an extension of the product range with additional products. These operations cause the cannibalization effect of offshoring as the increasing output of foreign-produced varieties crowds out demand for domestically produced goods. Therefore, as a result of the relocation and the cannibalization effect, our analysis in partial equilibrium clearly indicates that domestic labor demand will decrease in the presence of more offshoring. In general equilibrium, our analysis highlights adjustments through factor markets as an important transmission channel of external shocks. Assuming factor market clearing, domestic wages decrease as a response to the pressure on domestic labor. Therefore, endogenizing wages, our model is able to predict patterns in which firms even "re-relocate" entire product lines following a decline in offshoring costs and a delayed fall in wages.

From a theoretical point of view, the way we are thinking about offshoring as a relocation of production lines within MPFs is novel. However, the way offshoring is measured in the broad empirical literature on international production is in line with our definition. In a seminal contribution by Feenstra and Hanson (1996), final goods next to imported intermediates are directly included in the measurement of offshoring. Therefore, this way of measuring offshoring is directly related to our idea. Other empirical papers, such as Head and Ries (2002), Ebenstein et al. (2012), and Becker et al. (2013) measure offshoring activity in an industry by the total employment in foreign affiliates. We show that this empirical approach is consistent with our model.

Chapter 2 of this thesis is joint work with Lisandra Flach. In this chapter, we investigate, theoretically and empirically, the innovation strategies of MPFs, where we distinguish between investments in product and process innovation. This research is motivated by recent contributions to the international trade literature, which emphasize the importance of intra-firm adjustments through innovation in explaining the welfare gains from trade liberalization. The relevance of within-firm product expansion has already been highlighted earlier in this preface (see papers by Broda and Weinstein (2010) and Bernard et al. (2010), which highlight the importance of new product creations within existing firms). In addition, other empirical studies point out the relevance of firm's investments in cost-reducing process innovation as a large fraction of aggregate changes in industry-level productivity. For Spanish firms, Doraszelski and Jaumandreu (2013) show that, within sectors, between 65 percent and 90 percent of productivity growth arises through intra-firm productivity enhancing activities. These findings document the importance of innovation activities within firms next to the well-established intra-industry gains from entry and exit of firms.

The theoretical contribution of Chapter 2 is the modelling of a new framework of MPFs, which captures two types of innovation. Firms may decide to expand their product range or to lower production costs, and the net effect in terms of returns to innovation is a priori unclear. Our framework predicts that in a larger market, firms will invest more in both types of innovation as they can exploit economies of scale. However, the key feature of our theory is that the returns to both types of innovation are determined by industry-specific cost and demand linkages. We stress that these linkages can only occur in a multi-product setting. As a novel feature of our model, the strength of the demand and costs linkages varies across industries, which are distinguished according to the degree of product differentiation. To understand the role played by the degree of differentiation, one may consider firms in two industries with different scope for product differentiation - one industry with homogeneous products and one industry with highly differentiated products. Firms producing multiple products in the homogeneous industry have rather low returns from investing in new products as doing so crowds out demand for their existing products. Earlier in this preface, this effect has been described as the cannibalization effect. Contrary, investments in process-optimizing technologies may generate larger returns, since a firm can internalize spillover effects across production lines. Homogeneous products imply similar production processes and thus investments in the production process of one variety are applicable to a large fraction on the entire product portfolio of the firm. Obviously, for firms in a highly differentiated industry, the mechanism works exactly the other way round. Following this intuition, our model predicts that firms in homogeneous industries will invest more in process innovation, while firms in differentiated industries will focus more on product innovation.

We test the main predictions from the model using Brazilian firm-level data. This data has two important features. First, it contains detailed information on investments in product and process innovation in the period 1998-2000. Second, in this period, a major and unexpected exchange rate shock makes it possible to evaluate changes in market size. In January 1999, the Brazilian *real* devaluated unexpectedly by 25 percent within a month. We use this event and exploit it as a highly exogenous source of variation. Our empirical results reveal that firms increased their innovation efforts in both product and process innovation following the exchange rate devaluation. We argue that this is because the shock can be compared to an increase in market size as the currency devaluation made Brazilian products more competitive at home and abroad. Furthermore, we apply a continuous measure of the degree of differentiation at the industry-level and evaluate differential effects across industries. We confirm the predictions from our theory that firms in more differentiated industries invest more in product innovation, while firms in more homogeneous industries invest more in process innovation.

In Chapter 3, I address again the R&D portfolio of an MPF, focusing on the welfare implications of intra-firm adjustments. I show how distinguishing between different kinds of innovation in a multi-product setting can help to disentangle the welfare gains from trade. The motivation for this chapter is similar to the motivation for the previous chapter. There, I have already pointed out the relevance of within-firm innovations for aggregate changes in variety and productivity at the industry-level. In addition to the two types of innovation mentioned in Chapter 2, I introduce investments in the degree of product differentiation as a third important strategic variable that firms may want to determine. Next to the welfare analysis, this third component of innovation is the main theoretical contribution to the literature.

In most studies, the degree of product differentiation is regarded as a main component of the industry structure, which is treated as an exogenous variable. However, I show that, in contrast to single-product firms, MPFs have higher incentives to invest in product differentiation. The reason for this behavior has already been given in Chapter 2. There, it was shown that as a result of less cannibalization, the returns to product innovation rise in the degree of product differentiation. Hence, the innovating firm can dampen the negative externality of product innovation by investing in the degree of product differentiation. To avoid cannibalization among products, firms invest in new blueprints or product specific attributes such as differences in functional features or design. Furthermore, promotion activities such as advertisement or marketing campaigns help to highlight the differences between products. All these measures come along with fixed costs, however, they are implemented to differentiate the products within the portfolio and to reduce the cannibalization effect across these varieties. I show that consumers appreciate these investments as they value choosing from a broad and diversified product range.

In order to analyze welfare implications, I follow Melitz and Ottaviano (2008) and compute the indirect utility function for a quadratic specification of preferences. I show that consumers benefit from more variety (*love of variety*), *lower prices*, and, notably, from a higher degree of product differentiation. As the degree of product differentiation is endogenously chosen in my model, I stress the latter property of the utility function and refer to it as *love of diversity*. This implies that consumers value a given product range more when products are more differentiated. I argue that endogenizing the degree of product differentiation reveals an important channel through which globalization may affect the variety gains. Crucially, consumer welfare is not only determined by the absolute number of available products in an economy but also by the individual product features that distinguish these varieties. Having disentangled these three individual welfare channels helps me to discuss the gains from trade liberalization arising from intra-firm adjustments. A rising market size or falling trade costs enable firms to exploit economies of scale in innovation. This gives rise to increasing optimal investment levels as investment costs can be spread over more units of output. Therefore, economies of scale induce an MPF to enlarge and diversify its product range. Given the love of variety and love of diversity channels, this improves consumer welfare. Furthermore, I show that a higher volume of sales in a larger market is associated with technology upgrading. The resulting cost savings are passed on to consumers, leading to welfare gains from lower prices.

All three chapters of this dissertation are self-contained and include their own introductions and appendices such that they can be read separately. Hence, to facilitate reading within chapters, footnotes and equations are numbered independently in each chapter.

Chapter 1

Multi-Product Offshoring

1.1 Introduction

In the last decades, progress in communication and information technologies has changed the international organization of production. Markets are dominated by large multinational firms that control and manage production lines on a global scale. Global production networks enable firms to benefit from the generally lower labor costs in emerging countries. Against this background, industrialized countries fear a decline of jobs and pressure on wages. Recent academic research has identified two main channels by which offshoring affects domestic labor demand. Firstly, there is a relocation effect from the displacement of tasks that formerly were carried out domestically. Secondly, there are efficiency gains from vertical specialization that benefit domestic workers and increase domestic labor demand.[1]

In this chapter, we study the consequences of a different kind of offshoring: Off-

[0]This chapter is based on joint work with Carsten Eckel. When working on this chapter, we have benefited from comments by Daniel Baumgarten, Lisandra Flach, J. Peter Neary, Tobias Seidel, Mirjam Wuggenig, Stephen Yeaple, and participants at the IO and Trade Seminar at the University of Munich, the Workshop "Internationale Wirtschaftsbeziehungen" in Goettingen 2012, the European Trade Study Group in Leuven 2012, the Offshoring and International Production Conference in Tuebingen 2013, the Midwest Economic Theory and International Trade Meetings in Ann Arbor 2013, the Economic Geography and International Trade Meeting at CESifo 2014, and the SFB TR 15 Conference in Mannheim 2014.

[1]The efficiency or productivity effect of offshoring is stressed in recent contributions to the offshoring literature, such as Eckel (2003), Grossman and Rossi-Hansberg (2008), Rodriguez-Clare (2010), and Egger et al. (2013).

shoring of production lines within multi-product firms (MPFs). Analyzing firms that offer a bundle of horizontally linked products leads to important new insights into the effects of offshoring. Our results are crucially different from the well-known effects of relocating just parts of a production process of a single product. In particular, we argue that the efficiency effect of offshoring can only occur if the production of a single good is linked sequentially in two or more countries. Moreover, at least part of the production stages have to remain in the home country so that domestic employment can benefit from the higher productivity. If, however, the total production line is relocated, the latter effect vanishes. A firm, which produces a range of products, can decide for each product where it is produced most efficiently. We will show that it is the labor intensity of each product, which determines its optimal production location.

The relocation of a complete production process not only prevents the efficiency effect of offshoring but causes a cannibalization effect of offshoring that has not been discussed in the literature. If the products within the product range of an MPF are horizontally differentiated, the introduction of a new product will create a negative demand externality on all other products of this firm. This is typically referred to as the cannibalization effect and plays a big role in our analysis. Giving a firm the opportunity to offshore production will lead to a relocation of labor-intensive products and to an extension of the product range with additional products. We show that both operations will cannibalize output of domestically produced goods and reduce demand for labor in the home country.

A growing literature on MPFs stresses horizontal relationships between products within the boundaries of a single firm and analyzes the effects of globalization on the product range of a firm. Bernard et al. (2010) emphasize this as a new margin of firm adjustment, which Eckel and Neary (2010) refer to as intra-firm extensive margin. Within a multi-product framework, we investigate how improvements in the opportunities for offshoring affect the geographic organization and the product range of an MPF. For this purpose, we set up a general oligopolistic equilibrium (GOLE) model with MPFs and enrich this framework by introducing the firm's opportunity to offshore the production of multiple varieties to a low-wage emerging country. Varieties within a firm's product line are linked on the cost side through a flexible manufacturing technology, which captures the idea that - besides a core competence - an MPF can expand its portfolio with varieties that are less efficient in production. When producing abroad, a firm can use the same production technology as in the home country but additionally it has to bear offshoring costs.

We derive our results in partial and in general equilibrium. As a main result in partial equilibrium, we find that more products are produced abroad when prospects for offshoring improve. Furthermore, savings from lower offshoring costs lead to an extension of the product portfolio as the opportunity to produce labor-intensive products abroad enlarges the profit maximizing product range of an MPF. In a model where firms internalize demand linkages, rising outputs of foreign-produced varieties and additional varieties in the portfolio are crowding out domestic production, that does not benefit from lower offshoring costs. We stress this cannibalization effect as an important transmission channel that is specific to MPFs. In our model, in addition to the well-established relocation effect, cannibalization hits domestic production. For this reason, the analysis in partial equilibrium clearly indicates that domestic labor demand will decrease in the presence of more offshoring.

In general equilibrium, our analysis highlights adjustments through factor markets as an important transmission channel of external shocks on both the cutoff variety and the product range.[2] With endogenous domestic wages the results are not as clear cut anymore. It is no longer apparent that more products will be produced offshore with falling offshoring costs. We show that the more domestic production benefits from falling domestic wages the more likely is the partial result reversed in general equilibrium. Therefore, our model is able to predict patterns in which firms "re-relocate" entire product lines following a decline in offshoring costs and a delayed fall in wages.

Our model builds on and extends two strands of the existing literature in international trade on both MPFs and offshoring. Particularly with regard to the connection of both strands, Baldwin and Ottaviano (2001) come up with a multi-product setting where oligopolistic firms may produce some varieties in one country and other varieties in another. However, they explain intra-firm trade patterns akin to reciprocal dumping à la Brander and Krugman (1983) and not via factor price differences

[2] The cutoff variety is defined as the product where the firm is indifferent concerning the optimal production location. It is characterized by equal production costs in the home country and the offshore destination.

across countries. Hence, their approach is not associated with “offshoring” per se. In a recent paper, Yeaple (2012) extends a framework by Bernard et al. (2011) with a proximity-concentration trade-off. In his setting, firms produce multiple products for multiple countries and choose whether to export from the home country or to manufacture locally. Unlike to our model, his focus is not on wage differentials between countries but on firm heterogeneity with respect to managerial expertise. Managers deliver expertise to foreign affiliates, which means that firms with a higher manager efficiency tend to build foreign affiliates rather than to export to foreign countries. In an empirical analysis, McCalman and Spearot (2013) examine the role of vertical product differentiation in the decision where to produce a specific variety. Using a dataset of light truck sales in the US, Canada and Mexico, they study the location decision of final assembly. The patterns of offshoring that they find can be explained by the labor intensity in the automobile production. Furthermore, it is consistent with one of our theoretical predictions that foreign output is produced at a lower scale.

We also contribute to the large literature on international production. Our way to determine the cutoff variety between domestic and foreign production is reminiscent of a key contribution to the offshoring literature by Feenstra and Hanson (1996). While in their theoretical model, offshoring takes the form of relocating labor-intensive activities of a single manufactured good, they adopt a more general definition of offshoring in the empirical part.[3] Next to imports of intermediate goods, they further include final goods that are sold under the brandname of a firm in their definition of offshoring. Therefore, this measurement of offshoring is directly related to our way of defining offshoring as the relocation of complete production lines. By including final goods in their measure of offshoring, Feenstra and Hanson do better at explaining wage patterns and employment changes for the United States.[4] Other empirical papers measure offshore activity by the total employment of foreign affiliates. Using this kind of measure, authors typically think of capturing the relocation of vertically related tasks or the replication of domestic production abroad (horizontal FDI). However, we show that this way of measuring international activity is

[3] Feenstra and Hanson (1996) refer to this phenomenon as outsourcing.

[4] Feenstra and Hanson (1996) argue that previous studies like Berman et al. (1994) and Lawrence (1994) did not find an impact of offshoring on U.S. wages because of their narrow definition of offshoring.

perfectly consistent to what we call multi-product offshoring.
Existing theoretical research on MPFs is concerned mainly with the product market side of the economy. The main question which is tried to be answered is how MPFs absorb international trade. Intra-firm product switching is frequent and contributes like firm entry and exit to the evolution of aggregate outcomes in an industry.[5] The literature differs in the way of modelling the demand for and the decision to supply multiple products and in the assumptions about market structure. Most recent models assume that markets can be characterized by monopolistic competition, in which firms produce a large number of products but are themselves infinitesimal small in scale in the economy (see Arkolakis and Muendler (2010), Bernard et al. (2011), Nocke and Yeaple (2013), and Mayer et al. (2014)). Our model is built along the lines of Eckel and Neary (2010) who set up a different approach and assume that markets are oligopolistic. Their underlying market structure highlights as an important feature the cannibalization effect, which also plays a crucial role in our model.[6] Next to these demand linkages, Eckel and Neary's approach incorporates cost linkages between varieties in the form of flexible manufacturing.[7]
The remainder of the article is structured as follows. Section 2 recaps the basic model of Eckel and Neary (2010) and incorporates offshoring into this framework. Subsequently, we provide comparative static results of falling offshoring costs. Section 3 shows how these results transform when wages are endogenized in general equilibrium. Section 4 concludes and summarizes results. Mathematical derivations and a numerical simulation of our model are presented in the Appendix.

1.2 The Model

To conduct our analysis, we rely on the multi-product framework with flexible manufacturing proposed by Eckel and Neary (2010). We introduce a model where firms on grounds of efficiency seeking can relocate the production of labor-intensive goods

[5] Bernard et al. (2010) report changing product ranges for more than 50 percent of US firms within five years whereby one-half of those firm both added and dropped at least one product.

[6] The cannibalization effect is also considered in recent articles by Feenstra and Ma (2008) and Dhingra (2013).

[7] The concept of flexible manufacturing is also used in Milgrom and Roberts (1990), Eaton and Schmitt (1994), Norman and Thisse (1999), and Eckel (2009).

abroad. Our setup consists of two countries, Home and Foreign, and a large world market. There is a continuum of identical industries in Home, whereby the output produced in each of these industries is sold on the world market. Foreign is a low wage emerging country and acts as a potential destination for an affiliate. We begin this section with the analysis of one single sector by considering the behavior of the consumers in the world market and the optimal firm behavior in this industry.

1.2.1 Consumer Behavior: Preferences and Consumer Demand

We assume that L^W consumers in the world market maximize their utility defined over the consumption of differentiated products. Referring to the model of Eckel and Neary (2010), we maintain the specification of preferences in the form a two-tier utility function.[8] The upper tier is an additive function of a continuum of sub-utility functions over industries z, where z varies over the interval $[0, 1]$, given by

$$U\left[u\left(z\right)\right]=\int_{0}^{1}u\left(z\right)dz. \tag{1.1}$$

The representative consumer's sub-utility is defined over per variety consumption $q(i, z)$ with $i \in \Omega$ and total consumption $Q \equiv \int_{i\in\Omega} q(i, z)di$, where Ω is a set of differentiated goods offered in industry z. To be more specific, we assume

$$u\left(z\right)=aQ-\frac{1}{2}b\left[\left(1-e\right)\int_{i\in\Omega}q(i,z)^{2}di+eQ^{2}\right]. \tag{1.2}$$

Eq. (1.2) has a standard quadratic form, where a, b denote non-negative preference parameters and e is an inverse measure of product differentiation, which lies between 0 and 1. Lower values of e imply that products are more differentiated and hence less substitutable. In the event of $e = 1$, consumers have no taste for diversity in products and demand depends on aggregate output only. Consumers maximize utility in Eqs. (1.1) and (1.2) subject to the budget constraint $\int_0^1 \int_{i\in\Omega} p(i, z)q(i, z)didz \leq I$, where $p\left(i, z\right)$ denotes the price for variety i in industry z and I is individual income. This

[8]These preferences combine the continuum quadratic approach to symmetric horizontal product differentiation of Ottaviano et al. (2002) with the preferences in Neary (2009).

yields the following linear inverse individual demand function:

$$\lambda p(i,z) = a - b\left[(1-e)q(i,z) + eQ\right], \tag{1.3}$$

where λ is the marginal utility of income, the Lagrange multiplier attached to the budget constraint. Market-clearing imposes that each firm faces a market demand $x(i,z)$ that consists of the aggregated demand of all consumers in the world market $L^W q(i,z)$. For the inverse world market demand, we get

$$p(i,z) = a' - b'\left[(1-e)x(i,z) + eX\right], \tag{1.4}$$

where $a' \equiv \frac{a}{\lambda}$ is the consumers' maximum willingness to pay and $b' \equiv \frac{b}{\lambda L^W}$ is an inverse measure for the market size. Finally, $X \equiv \int_0^\delta x\left(i,z\right)di$ represents the total volume of varieties produced and consumed in industry z. Note that X is defined over the goods actually consumed with $i \in [0,\delta]$, which is a subset of the potential products Ω. With no quasi-linear term in Eq. (1.2), the value of λ is not constant, which implies that a' and b' are endogenously determined in general equilibrium. However, with a continuum of industries, we may assume that each firm takes these parameters as given. Hence, each firm has market power in its own market but it is small in the economy as a whole. This assumption permits a consistent analysis of oligopoly in general equilibrium. As it has become standard in the literature, we choose the marginal utility of income as the numeraire and set λ equal to one (see Neary (2009) for further discussion).

1.2.2 Firm Behavior: Costs and Technology of MPFs

This section considers technology and optimal firm behavior in industry z.[9] We focus on intra-firm adjustments, so competition between firms plays only a second-order role. To keep the analysis as simple as possible, we focus on the monopoly case. Extending the analysis to oligopoly is straightforward.[10] According to that, each industry z is characterized by exactly one firm whose objective it is to maximize

[9] We concentrate on symmetric industries and drop the industry index z in the following analysis. We consider this index again when we aggregate over all industries and turn to the level of the economy as a whole in general equilibrium.

[10] The interested reader is referred to the Appendix in Eckel et al. (2011).

profits by choosing both the scale and scope of production, as well as choosing the optimal location for producing each specific variety. When choosing the optimal location for production, firms seek to reduce costs by producing labor-intensive goods offshore where a comparative advantage exists due to lower wages. For simplicity, we assume no fixed costs for both domestic and foreign production.

In our model, an MPF is characterized by a core competence and flexible manufacturing. Technology is firm-specific and, therefore, it can be applied correspondingly in Home and in Foreign. As in Grossman and Rossi-Hansberg (2008), technology is transferable as a home firm will use its own technology when performing a task abroad. Flexible manufacturing is characterized by one core competence, in which the firm is most efficient in fabrication. Furthermore, an MPF can produce additional varieties with rising marginal costs.

Production costs in our model comprise both a product-specific and a monitoring component (managerial effort), which we assume to be zero for production at home. This assumption implies that the ability to monitor varies with distance. Managerial effort is needed to supervise production and to provide the firm's technology abroad.[11] By incorporating these costs, we try to capture the more general idea that aggravated monitoring through managers, less skilled workers, worse infrastructure, or inferior contractual enforcement, affect production in emerging countries. In the following analysis, we refer to this cost component as offshoring costs. To put it formally, we assume a Ricardian technology where domestic (foreign) production costs $c(i)$ ($c^*(i)$) are given by

$$c(i) = w\gamma(i) \text{ and} \tag{1.5}$$

$$c^*(i) = w^*(\gamma(i) + t), \tag{1.6}$$

with $\gamma(i)$ denoting the labor input coefficient for variety i, w (w^*) being the wage level in Home (Foreign) and finally t representing the offshoring costs.[12] Latter is measured in labor costs and is the same for all products assembled abroad. As we are analyzing the relocation of total production lines and not the relocation of just parts of a production process, the assumption that t is identical for all offshored

[11] See for example Grossman and Helpman (2004). They assume that a principal is able to observe the manager's efforts at a lower cost when the manager's division is located near to the firm's headquarters as compared with when it is located across national borders.

[12] Foreign variables are denoted by an asterisk throughout.

varieties seems fair. Technology is firm- and not country-specific, therefore $\gamma(i)$ is the same in both countries. We assume the following properties: $\gamma(0) = \gamma^0$ and $\frac{\partial c}{\partial i} = \frac{\partial \gamma}{\partial i} w > 0$.

Closed Economy Without offshoring, optimal firm behavior is composed of maximizing total firm profits both with regard to scale and to scope. Considering the technology assumptions above and denoting the scope of the product portfolio by δ, profits are given by

$$\Pi = \int_0^\delta [p(i) - c(i)]\, x(i) di. \tag{1.7}$$

Firms simultaneously choose the quantity produced of each good and the mass of products produced. Maximizing profits in Eq. (1.7) with respect to scale $x(i)$ implies the first-order condition for scale:

$$\frac{\partial \Pi}{\partial x(i)} = p(i) - c(i) - b' [(1-e)x(i) + eX] = 0 \tag{1.8}$$

that leads to the optimal output of a single variety

$$x(i) = \frac{a' - w\gamma(i) - 2b'eX}{2b'(1-e)} \tag{1.9}$$

with $X \equiv \int_0^\delta x(i)di$ denoting total firm scale.[13] The negative impact of total firm scale X on the output of a single variety displays the cannibalization effect: $\frac{\partial x(i)}{\partial X} = -\frac{e}{(1-e)} < 0$. An MPF internalizes the effect that increasing output of a certain variety lowers prices for this, as well as, for all other varieties in the firm's product range. This effect only exists if $e > 0$, i.e. if products are not perfectly differentiated. Furthermore, Eq. (1.9) shows that, given its total output, a firm produces less of each variety the further away it is from its core competence. Given the symmetric structure of demand, this means that a firm charges higher prices for products that are further away from its core competence (see Eckel and Neary (2010), p.193 for a detailed analysis).

[13] The second-order condition of this maximization problem is: $\frac{\partial^2 \Pi}{\partial x(i)^2} = \frac{\partial p(i)}{\partial x(i)} - b'(1-e) - b'e\frac{\partial X}{\partial x(i)} < 0$.

In the next step, we consider the firm's optimal choice of product line. MPF's add new products as long as marginal profits are positive. Maximizing Eq. (1.7) with respect to scope implies the respective first-order condition[14]

$$\frac{\partial \Pi}{\partial \delta} = [p(\delta) - c(\delta)]x(\delta) = 0. \tag{1.10}$$

From Eq. (1.8), we know that the profit on the marginal variety $[p(\delta) - c(\delta)]$ cannot be zero. The firm adds new varieties up to the point where the marginal cost of producing the marginal variety equals the marginal revenue at zero output. The profit maximizing product range implies that the output of the marginal variety $x(\delta)$ is zero. Using Eq. (1.9) and setting $x(\delta)$ equal to zero yields

$$c(\delta) = a' - 2b'eX. \tag{1.11}$$

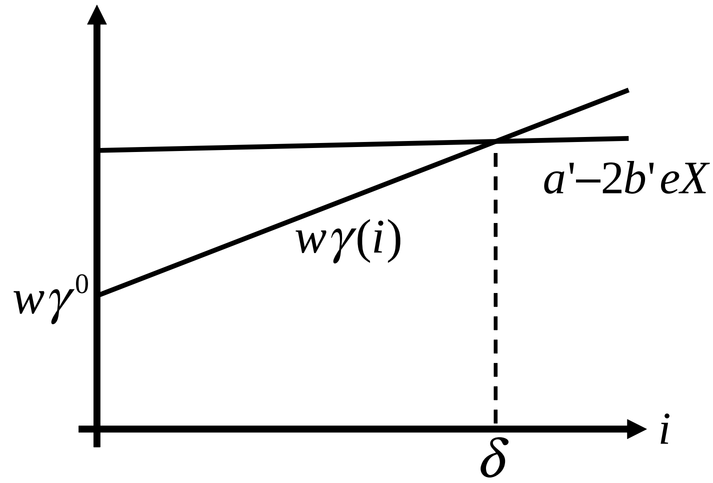
Comparing Eqs. (1.9) and (1.11), we see that firms add new varieties to their product portfolio until optimal output of the marginal variety falls to zero. Inspecting Eq. (1.11) reveals the cannibalization effect, which influences the scope of production: $\frac{\partial \delta}{\partial X} = -\frac{b'e}{\partial c(\delta)/\partial \delta} < 0$. Figure 1.1 illustrates the first-order condition for scope and determines the profit-maximizing product range.

Open Economy So far, we have implicitly assumed that the offshoring costs t were prohibitively high, so that all production was located in the home country. As globalization leads to improvements in information technology and reductions in communication costs, we analyze a decrease in the parameter t, which implies that firms can enjoy benefits of lower factor prices and thus gains from relocating labor-intensive products to a low-wage location. In our model, the motive for offshoring is efficiency-seeking, which means that the necessary condition for offshoring is: $w^* < w$. The sufficient condition for offshoring is that the offshoring costs are below a critical value: $t < t^{crit}$. The critical value of offshoring costs can be calculated as

$$t^{crit} = \frac{(a' - 2beX)(w - w^*)}{ww^*}. \tag{1.12}$$

[14]The second-order condition of this maximization problem is: $\frac{\partial^2 \Pi}{\partial \delta^2} = [p(\delta) - c(\delta)] \frac{\partial x(\delta)}{\partial \delta} < 0$, as $\frac{\partial c(\delta)}{\partial \delta} > 0$ and, thus, $\frac{\partial x(\delta)}{\partial \delta} = -\frac{1}{2b'(1-e)} \frac{\partial c(\delta)}{\partial \delta} < 0$.

Figure 1.1: Profit Maximizing Product Range



It is straightforward to see that the critical value of offshoring costs is rising in the wage differential between Home and Foreign.

In the analysis below, we refer to cases in which offshoring cost are sufficiently low, so there is a fragmentation of production into domestic and foreign-produced varieties. We define $\widetilde{\delta}$ as the cutoff variety. For variety $\widetilde{\delta}$, the firm is indifferent concerning its optimal production location. Varieties with a lower labor input coefficient than $\widetilde{\delta}$ are produced onshore, whereas varieties with a higher labor input coefficient are produced offshore. Combining Eqs. (1.6) and (1.9), gives the optimal scale of a foreign-produced variety:

$$x^*(i) = \frac{a' - w^*(\gamma(i) + t) - 2b'eX}{2b'(1-e)}. \tag{1.13}$$

Given that the marginal variety is produced in Foreign, the profit maximizing product range is defined by

$$w^*(\gamma(\delta) + t) = a' - 2b'eX. \tag{1.14}$$

In the open economy, an MPF faces a third maximization problem, next to optimal scale and scope of production. Now, the firm has also to determine the profit maximizing geographic location of production. Analogous to Eq. (1.7), total profits in the open economy are given by

$$\Pi = \int_{0}^{\widetilde{\delta}} (p(i) - c(i))\, x(i) di + \int_{\widetilde{\delta}}^{\delta} (p^*(i) - c^*(i))\, x^*(i) di, \tag{1.15}$$

with the first integral being total profits from domestic production and the second integral being the equivalent for foreign production. With Eq. (1.8) and total firm output X being composed of domestically and foreign-produced goods as

$$X = \int_{0}^{\widetilde{\delta}} x(i) di + \int_{\widetilde{\delta}}^{\delta} x^*(i) di, \tag{1.16}$$

we can rearrange Eq. (1.15):

$$\Pi = (1 - e)b' \left[\int_{0}^{\widetilde{\delta}} x(i)^2 di + \int_{\widetilde{\delta}}^{\delta} x^*(i)^2 di \right] + b'eX^2. \tag{1.17}$$

Maximizing Eq. (1.17) with respect to the optimal cutoff of production $\widetilde{\delta}$ leads to

$$x(\widetilde{\delta}) = x^*(\widetilde{\delta}). \tag{1.18}$$

Formal details of the derivation can be found in the Appendix.

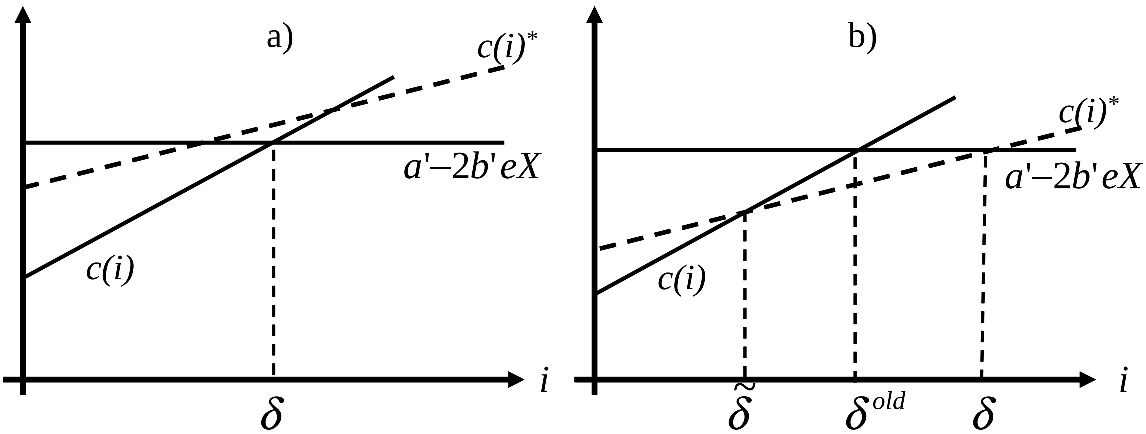
Lemma 1.1 *An MPF chooses the optimal cutoff level of production $\widetilde{\delta}$ exactly at that product where optimal scale in Home and in Foreign are the same. Combining Eqs. (1.9) and (1.13), this means that for variety $\widetilde{\delta}$ the firm is just indifferent concerning the location of production because costs are identical, i.e.*

$$w\gamma(\widetilde{\delta}) = w^*(\gamma(\widetilde{\delta}) + t). \tag{1.19}$$

To visualize our analysis, we illustrate the effects of falling offshoring costs in Figure 1.2. In Figure 1.2a), production of the whole portfolio is accomplished in Home as offshoring costs are prohibitively high. In Figure 1.2b), offshoring cost are below the critical value in Eq. (1.12). We observe that varieties $i \in [0; \widetilde{\delta}]$ are still produced in

Home, as their production is efficient enough, so the benefits of lower foreign wages do not prevail the offshoring costs. Production of varieties $i \in]\widetilde{\delta}; \delta^{old}[$ is relocated, as these goods can be produced at a lower cost in Foreign. Products $i \in]\delta^{old}; \delta[$ constitute an extension of the firm's product range. The MPF adds these varieties at the intra-firm extensive margin, whereby these goods would not be offered in case of producing exclusively in Home. The specification of our model suggests that an MPF produces exactly those varieties offshore, where its efficiency is relatively low.

Figure 1.2: Effects of Falling Offshoring Costs

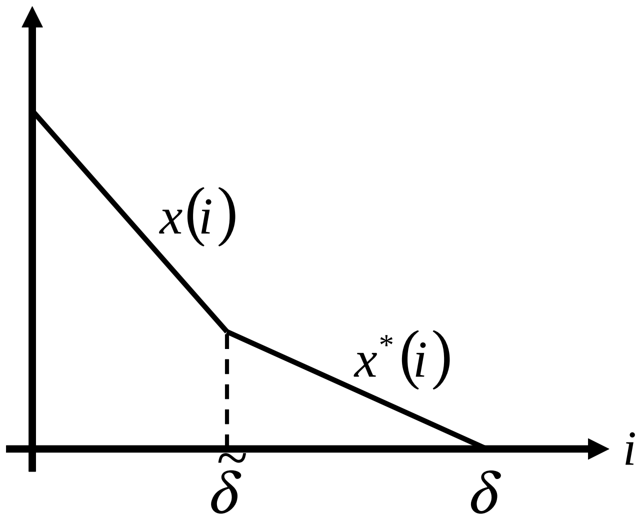


We conclude this section with a graphical illustration of the main properties of our model in Figure 1.3. The graph portrays optimal scale of production for the entire portfolio across the two production locations. We will use this graph in the next section as a useful tool in the comparative statics analysis. Figure 1.3 shows that due to the underlying flexible manufacturing technology, output of the core competence is the highest. At the cutoff $\widetilde{\delta}$ $\left(x\left(\widetilde{\delta}\right) = x^{*}\left(\widetilde{\delta}\right)\right)$ the firm switches to foreign production. Therefore, the slope of the curve changes at this point. Finally, the profit maximizing product range is pinned down at $x^{*}(\delta) = 0$.

1.2.3 Comparative Statics

We still assume that t is below its critical value determined in Eq. (1.12), so the firm engages in foreign production. In the comparative statics, we analyze the effect

Figure 1.3: Output Schedule



of better prospects for offshoring on the geographic organization (optimal cutoff) and on the profit-maximizing product range. Furthermore, we investigate the impact of reduced costs of offshoring on the output of domestic and foreign-produced varieties, as well as on total firm output. These endogenous variables of our model $x(i)$, $x^*(i)$, δ, X, and, $\widetilde{\delta}$ are determined in Eqs. (1.9), (1.13), (1.14), (1.16), and, (1.19) respectively. Totally differentiating this system of equations generates the comparative-static effects of decreasing offshoring costs t.

Recent academic research on MPFs brings forth varying results on the effects of globalization on the product range of a firm. A set of papers, including Eckel and Neary (2010), Bernard et al. (2011), and Mayer et al. (2014) show that MPFs will reduce their product ranges in response to trade liberalization. Increased competition forces firms to drop their worst performing products. In Feenstra and Ma (2008), increasing the market size leads to an expansion of the product range. Very recently, Qiu and Zhou (2013) show that the most productive firms in an economy may expand their product scope after globalization. In this chapter, we do not focus on the competition and market size effects of globalization. Globalization does also mean that access to foreign production locations is facilitated. Having the latter interpretation in mind, we can clearly show that the product scope increases in response to globalization.

Proposition 1.1 *If t is below the critical value determined in Eq. (1.12), falling offshoring costs induce an MPF to add new products at the intra-firm extensive margin, i.e.*

$$\frac{d\ln\delta}{d\ln t} = -\frac{\Delta_2 t}{\Delta_1 \gamma'(\delta)\,\delta} < 0, \tag{1.20}$$

where: $\Delta_1 = (1 - e + e\delta) > 0$ *and* $\Delta_2 = \left(1 - e + e\tilde{\delta}\right)$.

This result can be visualized in Figure 1.2b). A decrease in t corresponds to a downward shift of the c^*-curve, which indicates an extension of the product range. In a next step, we want to discuss the effects of globalization on the domestic product range $\tilde{\delta}$. With respect to the large literature on international production, this aspect has been neglected so far in theoretical models. We find that better prospects for offshoring reduce the domestic product range and incentivize a firm to relocate marginal varieties.

Proposition 1.2 *Falling offshoring costs make foreign production more attractive and thus lead to an efficiency-seeking relocation of production from the high-wage country to the low-wage country, i.e.*

$$\frac{d\ln\tilde{\delta}}{d\ln t} = \frac{w^* t}{(w - w^*)\,\gamma'\left(\tilde{\delta}\right)\tilde{\delta}} > 0. \tag{1.21}$$

As the wage rate in the home country w is higher than abroad w^*, the expression is strictly positive. The magnitude of this effect can be shown to depend on the point elasticity of the cost curve at the marginal variety: $\epsilon_{\gamma(\tilde{\delta})} \equiv \gamma'\left(\tilde{\delta}\right)\tilde{\delta}/\gamma\left(\tilde{\delta}\right)$. The latter stands for an inverse measure of flexibility of an MPF. High values of $\epsilon_{\gamma(\tilde{\delta})}$ imply that a change in $\tilde{\delta}$ will cause a large change in marginal costs. Hence, the change in the domestic product range following globalization will be smaller, the stronger domestic production costs react to a marginal decrease in $\tilde{\delta}$. To see this, we can rewrite Eq. (1.21) in $d\ln\tilde{\delta}/d\ln t = 1/\epsilon_{\gamma(\tilde{\delta})}$ using the indifference condition in Eq. (1.19). In Figure 1.2b), a decrease in t corresponds to a downward shift of the $c(i)^*$-curve, which is equivalent to shifting production abroad ($\widetilde{\delta}$ falls). Former domestically produced goods are now produced abroad. Referring to previous discussion, the effect is less pronounced in the case of steep cost curves.

So far, we have analyzed within-firm adjustments at the intra-firm extensive margin. In the next step, we focus on the output profiles (intensive margin) of domestically and foreign-produced varieties. Following a fall in t, offshore production gets cheaper and, therefore, foreign varieties are produced at a larger scale.

Proposition 1.3 *If t is below the critical value determined in Eq. (1.12), falling offshoring costs induce the firm to increase outputs of all foreign-produced varieties, i.e.*

$$\frac{d\ln x^*(i)}{d\ln t} = -\frac{w^*t}{2b'(1-e)\,x^*(i)}\frac{\Delta_2}{\Delta_1} < 0. \tag{1.22}$$

As an important feature in our model, we emphasize demand linkages between varieties in the product portfolio of a firm. Falling offshoring costs do not reduce domestic production costs but indirectly affect domestic output through the cannibalization effect. Rising output of foreign production crowds out domestic production as domestic varieties internalize the cannibalization effect.

Proposition 1.4 *The cannibalization effect induces an MPF to reduce outputs of all domestically produced varieties in consequence of falling offshoring costs, i.e.*

$$\frac{d\ln x(i)}{d\ln t} = \frac{e\left(\delta-\tilde{\delta}\right)}{\Delta_1}\frac{w^*t}{2b'(1-e)\,x(i)} > 0. \tag{1.23}$$

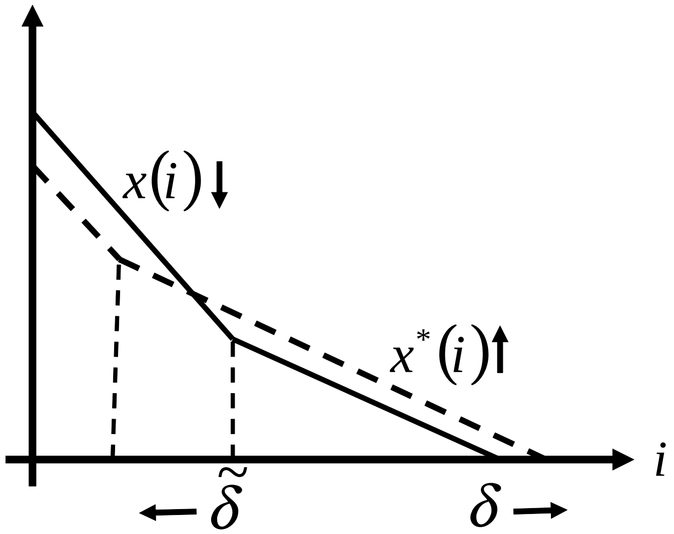
In the case of perfectly differentiated varieties, i.e. $e = 0$, domestic output is independent of foreign production and hence, the derivative in Eq. (1.23) is zero. With e being positive, varieties become substitutable and domestic output is crowded out by foreign production. However, it is straightforward to show that despite lower domestic output, total firm output X is increasing with falling offshoring cost. The positive impact of rising foreign output combined with the extension of the product range outweighs the negative impact of falling domestic output on total firm scale.

Proposition 1.5 *With falling offshoring costs, an MPF increases total firm output because of the higher scale of foreign-produced varieties and the extension of the product portfolio, i.e.*

$$\frac{d\ln X}{d\ln t} = -\frac{w^*\left(\delta-\tilde{\delta}\right)t}{2b'\Delta_1 X} < 0. \tag{1.24}$$

Formal details of all the derivations can be found in the Appendix of this chapter. To illustrate the effects of falling offshoring costs, we draw on the graphical tool developed in Figure 1.3. In Figure 1.4, the dotted line represents the situation after the reduction in t. Inspecting this graph reveals two negative effects on domestic production: A relocation effect from shifting production abroad and a cannibalization effect from rising foreign output. The latter effect is a new transmission channel specific to MPFs that we want to highlight. It results from the fact that with lower production costs abroad, output of foreign varieties and the foreign product range will increase. These intra-firm adjustments crowd out the production of domestic varieties, which does not benefit from lower production costs abroad. The main comparative static results are indicated by the arrows in Figure 1.4.

Figure 1.4: Output Schedule and Comparative Statics



1.2.4 Implications for the Measurement of Offshoring

From a theoretical point of view, the way we are thinking about offshoring as a relocation of production lines within MPFs is novel. However, the manner how offshoring is measured in the broad empirical literature on international production is similar to our definition. The measure of outsourcing which is used in Feenstra and Hanson (1996) is directly related to our definition, as it includes also final goods next to imported intermediates. The authors argue that this "must be included in any valid measure of outsourcing" (Feenstra and Hanson (1996), p.107). Many other papers that discuss offshoring from an empirical perspective use measurements of offshoring that respond not only to a relocation of vertically related processes, but also respond to what we call multi-product offshoring. Papers such as Head and Ries (2002), Ebenstein et al. (2012), and Becker et al. (2013) measure offshoring activity in an industry by the total employment of foreign affiliates. Using employment in foreign affiliates as a measure for offshoring is perfectly in-line with our model. To underline that measuring offshoring like this could also mean the type of offshoring that we have in mind, we calculate the total employment in foreign affiliates and show how it responds to better offshoring opportunities. In industry z, labor demand l^* for foreign-produced varieties is given by

$$l^*\left(z\right) = \int_{\widetilde{\delta}(z)}^{\delta(z)} \gamma(i) x^*(i) di. \tag{1.25}$$

It is determined by the scale and scope of foreign-produced varieties $i \in [\widetilde{\delta}; \delta]$. We derive total labor demand in the offshore destination L^* by integrating over all industries $z \in (0, 1)$

$$L^* = \int_0^1 l^*\left(z\right) dz = \int_0^1 \int_{\widetilde{\delta}(z)}^{\delta(z)} \gamma(i, z) x^*(i, z) di dz. \tag{1.26}$$

By substituting for $x\left(i\right)^*$ and evaluating the integral, we come up with the following equation

$$L^* = \frac{\left(\delta - \tilde{\delta}\right)\left[\left(a' - 2b'eX - w^*t\right)\mu_\gamma'^* - w^*\mu_\gamma''^*\right]}{2b'\left(1-e\right)}, \tag{1.27}$$

where $\mu_\gamma'^* \equiv \frac{1}{\delta - \tilde{\delta}} \int_{\tilde{\delta}}^{\delta} \gamma\left(i\right) di$ is the mean labor input of foreign-produced varieties and $\mu_\gamma''^* \equiv \frac{1}{\delta - \tilde{\delta}} \int_{\tilde{\delta}}^{\delta} \gamma\left(i\right)^2 di$ is the second moment around zero of the distribution of labor requirements. We totally differentiate Eq. (1.27) and analyze again the effects of better prospects for offshoring:

$$\frac{d\ln L^{*}}{d\ln t}=-\frac{w^{*}t}{2b'\left(1-e\right)L^{*}}\left\{\frac{\left(\delta-\tilde{\delta}\right)\mu_{\gamma}'^{*}\Delta_{2}}{\Delta_{1}}+\frac{\tilde{\delta}w^{*}\left(\gamma(\delta)-\gamma\left(\tilde{\delta}\right)\right)}{\left(w-w^{*}\right)\epsilon_{\gamma(\tilde{\delta})}}\right\}<0. \tag{1.28}$$

The latter expression clearly indicates that the total employment of foreign affiliates is increasing in falling offshoring costs. Therefore, measuring offshore activity by total employment of foreign affiliates captures the type of offshoring that we have in mind.

Lemma 1.2 *Falling offshoring costs increase total employment in the offshoring destination.*

1.3 General Equilibrium

The previous section analyzed the effects of falling offshoring costs on the product range, per variety output, total firm output and the optimal location of production. Up to this point, the approach was partial, since we did not consider endogenous changes in wages. Our analysis in partial equilibrium clearly yields a fall in domestic production, because, on the one hand, per variety output of domestic varieties gets crowded out and, on the other hand, varieties close to the cutoff are relocated with falling offshoring costs. In the next steps, we focus on new insights into the labor market effects from offshoring, which arise from the framework that we have presented so far. For this purpose, we introduce a simple labor market and show how domestic labor demand is affected by multi-product offshoring. Subsequently, we analyze again the comparative statics exercise of falling offshoring costs under consideration of labor market clearing.

1.3.1 Labor Market Clearing

In this section, we turn to the level of the economy as a whole and explore the general equilibrium effects of falling offshoring costs. To simplify the analysis, we assume that all industries are identical. In a first step, we need to specify how wages are determined. We assume a total labor supply L^S, that is supplied inelastically by the households in Home. Domestic labor demand in industry z is given by

$$l(z) = \int_0^{\widetilde{\delta}(z)} \gamma(i)\, x(i)\, di. \tag{1.29}$$

It is determined by the scale and scope of domestically produced varieties $i \in [0; \widetilde{\delta}]$. We derive total labor demand L in our economy by integrating over all industries $z \in (0, 1)$:

$$L = \int_0^1 l(z)\, dz = \int_0^1 \int_0^{\widetilde{\delta}(z)} \gamma(i, z) x(i, z) di dz. \tag{1.30}$$

Our main interest in this section is to determine the labor market effects of offshoring. In the previous section we have identified two effects of falling offshoring costs: A relocation effect and a cannibalization effect. The relocation effect affects the marginal variety $\widetilde{\delta}$ and the cannibalization effect affects the scale of domestic production $x(i)$. Totally differentiating domestic labor demand in Eq. (1.30) with respect to t yields:[15]

$$\frac{dL}{dt} = \underbrace{\gamma\left(\widetilde{\delta}\right) x\left(\widetilde{\delta}\right) \frac{d\widetilde{\delta}}{dt}}_{\text{relocation effect}} + \underbrace{\int_0^{\widetilde{\delta}} \gamma(i)\, \frac{dx(i)}{dt} di}_{\text{cannibalization effect}} > 0. \tag{1.31}$$

The first part of Eq. (1.31) describes the relocation effect and the second part stands for the cannibalization effect. Latter effect is new and is specific to MPFs. With falling offshoring costs, scale of foreign production rises because of lower production costs abroad. This behavior cannibalizes domestic production and reduces domestic labor demand.

Lemma 1.3 *For a given domestic wage, falling offshoring costs reduce domestic demand for labor through two channels. A relocation effect leads to a shift of labor-intensive domestic products abroad. Furthermore, domestic production internalizes a cannibalization effect of rising foreign output and is crowded out.*

[15] From inspection of propositions 1.2 and 1.4, we know that: $\frac{d\widetilde{\delta}}{dt} > 0$ and $\frac{dx(i)}{dt} > 0$.

In equilibrium, wages must adjust to ensure that total labor supply L^S equals total labor demand determined by the cutoff of domestic production $\widetilde{\delta}$ in all industries $z \in (0,1)$. This is reflected by the following labor-market equilibrium condition for the home country:

$$L^S = \int_0^1 l(z)\,dz = \int_0^1 \int_0^{\widetilde{\delta}(z)} \gamma(i,z)x(i,z)didz. \tag{1.32}$$

We can now substitute for $x(i)$ and evaluate the integral to obtain

$$L^S = \frac{\widetilde{\delta}\left[(a' - 2b'eX)\,\mu'_\gamma - w\mu''_\gamma\right]}{2b'(1-e)}, \tag{1.33}$$

with $\mu'_\gamma \equiv \frac{1}{\widetilde{\delta}}\int_0^{\widetilde{\delta}} \gamma(i)di$ being the mean labor input of domestically produced varieties and $\mu''_\gamma \equiv \frac{1}{\widetilde{\delta}}\int_0^{\widetilde{\delta}} \gamma(i)^2 di$ stands for the second moment around zero of the distribution of labor requirements. Combining Eq. (1.33) with the system of equations from the analysis in partial equilibrium, we can use the respective equations for investigating how firm-level adjustments respond to declining offshoring costs with endogenous wages. We derive the comparative statics results by totally differentiating all equations of the system. Formal details of all the derivations can be found in the Appendix.

1.3.2 Comparative Statics in General Equilibrium

One important issue in general equilibrium, which we want to analyze in the first place, is the effect of better prospects for offshoring on domestic factor prices w. In the previous sections, we have identified two negative impacts of offshoring on domestic labor demand: The relocation and the cannibalization effect. However, in equilibrium, total labor supply must equal total demand for labor. To ensure this equality, domestic wages must fall.

Proposition 1.6 *With falling offshoring costs, ceteris paribus, foreign production gets more attractive. To ensure labor market clearing in equilibrium, there are ad-*

justments on the labor market in the form of falling domestic wages, i.e.[16]

$$\frac{\Delta w}{w^* t}\frac{d\ln w}{d\ln t} = \left\{e\left(w-w^*\right)\gamma'\left(\tilde{\delta}\right)\left(\delta-\tilde{\delta}\right)\tilde{\delta}\mu'_{\gamma} + \Delta_1 w^*\left[\gamma(\delta)-\gamma\left(\tilde{\delta}\right)\right]\gamma\left(\tilde{\delta}\right)\right\} > 0. \tag{1.34}$$

Considering these labor market adjustments reveals that in general equilibrium falling offshoring costs not only make foreign production cheaper but also reduce production costs in the home country. The latter has important implications on the main variables of interest in our model, which we point out in the following.

With lower production costs in both countries, it is apparent that an MPF will increase its total scale:

$$\frac{d\ln X}{d\ln t} = -\frac{w^*\left(\delta-\tilde{\delta}\right)t}{2b'\Delta_1 X} - \frac{w\tilde{\delta}\mu'_{\gamma}}{2b'\Delta_1 X}\frac{d\ln w}{d\ln t} < 0. \tag{1.35}$$

The mathematical derivation and an expression where the change in wages is substituted can be found in the Appendix. Eq. (1.35) is the general equilibrium equivalent of Eq. (1.24). Comparing both equations immediately points out that due to the adjustment of factor prices (represented by the second fraction), the general equilibrium effect will be of greater magnitude than the partial equilibrium effect (represented by the first fraction). Within our framework, a larger firm scale X enhances cannibalization between varieties. Caused by falling domestic wages, the latter effect leads to a new channel that we have to consider when analyzing the repercussions of falling offshoring costs on the product range of a firm. We illustrate this channel in the following equation:

$$\frac{d\ln\delta}{d\ln t} = -\frac{\Delta_2 t}{\Delta_1\gamma'(\delta)\delta} + \frac{ew\tilde{\delta}\mu'_{\gamma}}{\Delta_1 w^*\gamma'(\delta)\delta}\frac{d\ln w}{d\ln t} < 0, \tag{1.36}$$

where the first part of Eq. (1.36) represents the partial effect, which is clearly of a negative sign. The second part of Eq. (1.36) is the additional channel in general equilibrium arising from the adjustment of wages. This effect is positive

[16] $\Delta = \left\{\left[(1-e)+e\left(\delta-\tilde{\delta}\right)\right]\tilde{\delta}\mu''_{\gamma}+e\tilde{\delta}^2\sigma^2_{\gamma}\right\}(w-w^*)\gamma'\left(\tilde{\delta}\right)+\Delta_1\gamma\left(\tilde{\delta}\right)w^*\left[\gamma(\delta)-\gamma\left(\tilde{\delta}\right)\right]\gamma\left(\tilde{\delta}\right)$ is the determinant of the system of equations. It is positive which ensures that the equilibrium is unique and stable.

and, therefore, works in the opposite direction as it induces the firm to increase its total output X. Inspecting Eq. (1.36) reveals that the general equilibrium effect is switched off for e being zero. With products being perfectly differentiated, there is no cannibalization of the rising total firm output X on the marginal varieties within the product range. However, we can analytically show that the result from partial equilibrium is reconfirmed even for $e > 0$. Therefore, the adjustments in general equilibrium only have a dampening effect on the product range, which is driven by the intensity of cannibalization determined by the differentiation parameter e. A proof for this result is provided in the Appendix.

Proposition 1.7 *Falling offshoring costs reduce costs in both production sites and hence enlarge total firm output X to a larger extend compared to partial equilibrium. Latter result dampens but does not reverse the effect of falling offshoring costs on the product range in general equilibrium. The dampening effect depends on the strength of cannibalization.*

In the next step, we focus our attention on the optimal geographic organization of an MPF. Regarding the optimal cutoff of production, we identify two opposing forces in general equilibrium following a fall in the parameter t. On the one hand, there is the direct effect of lower offshoring costs, which tends to shift production abroad (observed effect in partial equilibrium, see Eq. (1.21)). On the other hand, we find decreasing domestic wages, which brings forth an inventive to pull back production into the home country. The latter causes an ambiguity on the total effect of falling offshoring costs in general equilibrium, which can be seen in the following derivative:

$$\frac{\Delta}{w^* t}\frac{d\ln\tilde{\delta}}{d\ln t} = \Delta_1 \mu''_\gamma - e\left[\left(\delta - \tilde{\delta}\right)\gamma\left(\tilde{\delta}\right) + \tilde{\delta}\mu'_\gamma\right]\mu'_\gamma \gtrless 0. \tag{1.37}$$

We now focus on this ambiguity and investigate the causes that lie behind it. To begin with, Eq. (1.37) is positive for e being zero. With perfectly differentiated products, domestic varieties do not internalize cannibalization through rising outputs of foreign varieties (compare Eq. (1.23)). Thus, there is no reducing force on domestic labor demand via a lower scale of domestically produced varieties (the cannibalization effect of offshoring, stressed in Eq. (1.31)). Thereby, to ensure labor market clearing, domestic wages will decline less and the wage-effect will not dominate the better opportunities to offshore. With $0 < e < 1$, there is the possibility that Eq. (1.37) gets negative, i.e. with falling offshoring costs even more products are produced in Home. This happens if the general equilibrium adjustment of factor prices prevails the foreign cost reduction via lower offshoring costs.

To get some further intuition for this ambiguity, we investigate the effect of an *exogenous* change in domestic wages on domestic output. Differentiating optimal scale $x(i)$ in Eq. (1.9) with respect to the wage rate w yields:[17]

$$\frac{d\ln x(i)}{d\ln w} = \frac{w}{2b'(1-e)x(i)} \frac{\left[e\widetilde{\delta}\mu'_{\gamma} - \Delta_1\gamma(i)\right]}{\Delta_1} \lessgtr 0. \tag{1.38}$$

The algebraic sign of Eq. (1.38) behaves ambiguously. Outputs of varieties with a labor input coefficient $\gamma(i)$ far below the average μ'_{γ} may even fall with falling wages (i.e. for these varieties $\frac{d\ln x(i)}{d\ln w} > 0$). The reason for this is that varieties, which are very efficient in production, require just sparse labor input and hence, benefit slightly from falling wages. However, these varieties fully internalize the cannibalization effect through rising outputs of labor-intensive varieties, which benefit a lot from lower factor prices.[18] Latter results imply that varieties benefit more from falling wages the higher is their respective labor input. These insights are important features of our model, which can help to explain the ambiguous effects of lower offshoring costs on the cutoff variety $\widetilde{\delta}$.

From the total derivatives of our system of equations, we obtain two equations in $\frac{d\ln\widetilde{\delta}}{d\ln t}$ and $\frac{d\ln w}{d\ln t}$, given by[19]

$$\frac{d\ln\tilde{\delta}}{d\ln t} = \frac{w^*t}{(w-w^*)\gamma'\left(\tilde{\delta}\right)\tilde{\delta}} - \frac{w\gamma\left(\tilde{\delta}\right)}{(w-w^*)\gamma'\left(\tilde{\delta}\right)\tilde{\delta}} \frac{d\ln w}{d\ln t} \gtrless 0 \tag{1.39}$$

[17] The interested reader finds the effects of an exogenous change in domestic wages on all endogenous variables in the Appendix.

[18] The condition for the output of the core competence to fall with falling wages is : $\gamma(0) < \frac{e\widetilde{\delta}\mu'_{\gamma}}{\Delta_1}$. The cutoff variety $\widetilde{\delta}$ has the highest labor input coefficient $\gamma(\widetilde{\delta})$ in the domestic product range. The output of this variety $x(\widetilde{\delta})$ rises with falling wages: $\frac{d\ln x(\widetilde{\delta})}{d\ln w} < 0$.

[19] $\Delta_3 = \Big((a' - 2b'eX) - w\gamma(\tilde{\delta})\Big) > 0$. From the first-order condition of scope it becomes obvious that this expression is positive.

and

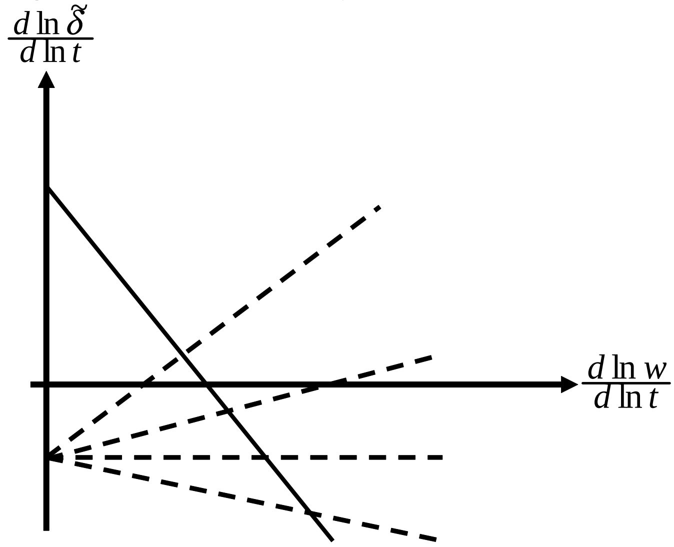
$$\frac{d\ln\tilde{\delta}}{d\ln t} = -\frac{w^{*}t\left(\delta-\tilde{\delta}\right)e\mu_{\gamma}'}{\Delta_1\Delta_3\gamma\left(\tilde{\delta}\right)} + \frac{w}{\Delta_3\gamma\left(\tilde{\delta}\right)}\left(\mu_{\gamma}''-\frac{e\tilde{\delta}\mu_{\gamma}'^{2}}{\Delta_1}\right)\frac{d\ln w}{d\ln t} \gtrless 0. \tag{1.40}$$

Eq. (1.39) follows immediately from the determination of the profit maximizing cutoff in Eq. (1.19). Eq. (1.40) is derived after some mathematical conversion from the labor market clearing condition in Eq. (1.33). Inspecting Eq. (1.39) reveals that the partial equilibrium result (the first part of the expression) is more likely to be reversed, the higher the adjustment in wages is weighted. From the analysis of Eq. (1.38), we know that varieties with high labor inputs will benefit more from reductions in factor prices. This insight can be reapplied to Eq. (1.39), where we observe the wage effect to be of greater impact, the higher is the labor input at the marginal variety $\gamma\left(\tilde{\delta}\right)$. By analogy, we apply this intuition to Eq. (1.40), where it becomes apparent that the higher is the mean labor input of domestic production μ_{γ}', the more likely the domestic wage reduction outweighs the cost advantage through lower offshoring costs. We summarize these insights in the following proposition.

Proposition 1.8 *In partial equilibrium, lower offshoring costs t lead to a distinct fall in $\widetilde{\delta}$ (i.e. $\frac{d\ln\widetilde{\delta}}{d\ln t} > 0$). This result does not necessarily hold in general equilibrium, which implies that it is possible that even more products are produced onshore with better opportunities of offshoring (i.e. $\frac{d\ln\widetilde{\delta}}{d\ln t} < 0$). This ambiguity is caused by the general equilibrium result of falling domestic wages. We show that the result in partial equilibrium is more likely to be reversed, the higher are the benefits of falling wages in the domestic production.*

We conclude this section by illustrating the ambiguity on $\widetilde{\delta}$ in a $\left\{\frac{d\ln\widetilde{\delta}}{d\ln t}, \frac{d\ln w}{d\ln t}\right\}$ space. Figure 1.5 illustrates Eqs. (1.39) and (1.40). For Eq. (1.39), the slope is clearly negative, whereas the slope of Eq. (1.40) depends on the sign of $\left(\mu_{\gamma}''-\frac{e\widetilde{\delta}\left(\mu_{\gamma}'\right)^{2}}{\Delta_1}\right)$. We take away from the graph that the more do domestic wages respond to changes in the offshoring costs, the more likely is a result contrary to the partial equilibrium case (an intersection of the two curves below the x-axis).

Figure 1.5: Cutoff Variety in General Equilibrium



By all means $\frac{d\ln\widetilde{\delta}}{d\ln t} < 0$, for $\mu''_{\gamma} \leq \frac{e\widetilde{\delta}\left(\mu'_{\gamma}\right)^2}{\Delta_1}$, which implies Eq. (1.40) to be horizontal or to be negatively sloped. If $\mu''_{\gamma} > \frac{e\widetilde{\delta}\left(\mu'_{\gamma}\right)^2}{\Delta_1}$, Figure 1.5 illustrates that the algebraic sign of $\frac{d\ln\widetilde{\delta}}{d\ln t}$ can be both negative or positive.

In the Appendix, we provide a numerical simulation of our model where we show that in fact, the result in partial equilibrium can be reversed in general equilibrium. Assuming specific parameter values and a linear cost function, we are able to document that there are cases in which $\frac{d\ln\widetilde{\delta}}{d\ln t} < 0$.

1.4 Conclusion

Although globalization of production has been discussed extensively in the literature, there is not yet a framework to study the relocation of whole varieties within the boundaries of a firm. In this chapter, we show that the relocation of entire production lines leads to new insights into the labor market outcomes of offshoring. Reversing the assumptions that processes within a firm are vertically related and that part of the production of a variety stays in the home country we have highlighted new multi-product specific transmission channels of offshoring. We set up a general oligopolistic equilibrium model of MPFs and offshoring, which allows us to study the consequences of globalization in the sense of declining costs of offshoring. We show that better prospects for offshoring affect the geographic organization and the product range of an MPF. Giving a firm the opportunity to offshore the production of labor-intensive products will lead to a broader product range. Considering the offshoring impacts on domestic employment, we highlight the cannibalization effect of foreign on domestic output, which hits domestic employment next to the well established relocation effect. Having wages endogenized, our model suggests ambiguous tendencies on the cutoff of production. The more do domestic wages respond to changes in offshoring costs and the higher are the benefits from lower wages in domestic production, the more likely is an even extended domestic production in an economy with increasing globalization. Therefore, our model is able to predict patterns in which firms re-relocate entire product lines following globalization and a decline in offshoring costs. One issue we did not consider in our model is welfare of workers. As our specification considers domestic production only and consumption takes place on a third market, workers suffer from declining wages and do not benefit from lower prices of final goods. Due to this construction it does not make sense to assess welfare as we can not make any statements concerning the real wages in our model.

1.5 Appendix

1.5.1 Proof of Lemma 1.1

In the open economy scenario, an MPF has to determine the profit maximizing geographic location of production. In the following, we will sketch this maximization problem. From the first-order condition for scale in Eq. (1.8), we know:

$$p(i) - c(i) = b'(1-e)x(i) + b'eX, \tag{1.41}$$

which inserted in the open economy total profits in Eq. (1.15) leads to

$$\frac{\Pi}{b'} = (1-e)\int_0^{\widetilde{\delta}} x(i)^2 di + eX\int_0^{\widetilde{\delta}} x(i)di + (1-e)\int_{\widetilde{\delta}}^{\delta} x^*(i)^2 di + eX\int_{\widetilde{\delta}}^{\delta} x^*(i)di. \tag{1.42}$$

Given that $X = \int_0^{\widetilde{\delta}} x(i)di + \int_{\widetilde{\delta}}^{\delta} x^*(i)di$, we derive Eq. (1.17). To identify a condition for an optimally chosen cutoff variety $\widetilde{\delta}$, we maximize Eq. (1.17) with respect to $\widetilde{\delta}$. This implies the following first-order condition:

$$\frac{1}{b'}\frac{d\Pi}{d\widetilde{\delta}} = (1-e)\left[\int_0^{\widetilde{\delta}} 2x(i)\frac{dx(i)}{d\widetilde{\delta}}di + \int_{\widetilde{\delta}}^{\delta} 2x^*(i)\frac{dx^*}{d\widetilde{\delta}}di\right] \tag{1.43}$$

$$+(1-e)\left[x(\widetilde{\delta})^2 - x^*(\widetilde{\delta})^2\right] + (1-e)x^*(\delta)\frac{d\delta}{d\widetilde{\delta}} + 2eX\frac{dX}{d\widetilde{\delta}} = 0.$$

With $x^*(\delta) = 0$, $\frac{dx(i)}{d\widetilde{\delta}} = \frac{dx^*(i)}{d\widetilde{\delta}} = -\frac{e}{1-e}\frac{dX}{d\widetilde{\delta}}$, and some mathematical conversion, we derive

$$\frac{1}{b'}\frac{d\Pi}{d\widetilde{\delta}} = (1-e)\left[x(\widetilde{\delta})^2 - x^*(\widetilde{\delta})^2\right] = 0. \tag{1.44}$$

1.5.2 Comparative Statics in Partial Equilibrium

In the following, we show how to derive the comparative static results of the model. In our model, the equilibrium is determined by the following system of equations:

$$w\gamma(\widetilde{\delta}) = w^*(\gamma(\widetilde{\delta}) + t) \tag{1.45}$$

$$x(i) = \frac{a' - w\gamma(i) - 2b'eX}{2b'(1-e)} \tag{1.46}$$

$$x^*(i) = \frac{a' - w^*(\gamma(i) + t) - 2b'eX}{2b'(1-e)} \tag{1.47}$$

$$X = \int_0^{\widetilde{\delta}} x(i)di + \int_{\widetilde{\delta}}^{\delta} x^*(i)di \tag{1.48}$$

$$w^*(\gamma(\delta) + t) = a' - 2b'eX \tag{1.49}$$

We can reduce this system of equations to two equations in $\widetilde{\delta}$ and δ. In a first step, we substitute Eqs.(1.46) and (1.47) in Eq.(1.48) and derive total output as

$$X = \frac{1}{2b'\Delta_1}\left\{a'\delta - w\int_0^{\widetilde{\delta}} \gamma(i)\, di - w^*\left[\int_{\widetilde{\delta}}^{\delta} \gamma(i)\, di + t\left(\delta - \widetilde{\delta}\right)\right]\right\}. \tag{1.50}$$

In a second step, we combine the latter expression with Eq. (1.49), which leads to

$$w^*(\gamma(\delta)+t) = a' - \frac{e}{\Delta_1}\left\{a'\delta - w\int_0^{\widetilde{\delta}} \gamma(i)\, di - w^*\left[\int_{\widetilde{\delta}}^{\delta} \gamma(i)\, di + t\left(\delta - \widetilde{\delta}\right)\right]\right\}. \tag{1.51}$$

Eqs. (1.45) and (1.51) constitute two equations in two endogenous variables: $\widetilde{\delta}$ and δ. By totally differentiating this system of equations, we derive our results in partial equilibrium. We show the total derivatives of Eqs. (1.45) and (1.51) in the next section of this Appendix.

1.5.3 Comparative Statics in General Equilibrium

In general equilibrium, we add the labor market clearing condition to our system of equations from the previous section. By substituting Eq. (1.49) into the labor market clearing condition in Eq. (1.33), we derive

$$L = \frac{\left(w^*(\gamma(\delta)+t)\right)\widetilde{\delta}\mu'_\gamma - w\widetilde{\delta}\mu''_\gamma}{2b'(1-e)}. \tag{1.52}$$

The combination of Eqs. (1.45), (1.51), and (1.52) determines the general equilibrium of our model. In the total derivatives, we take into account that domestic wages are endogenously determined in the domestic labor market. For deriving the following results, note that $\frac{d}{d\widetilde{\delta}}(\widetilde{\delta}\mu'_\gamma) = \gamma\left(\widetilde{\delta}\right)$ and $\frac{d}{d\widetilde{\delta}}(\widetilde{\delta}\mu''_\gamma) = \gamma\left(\widetilde{\delta}\right)^2$. Totally differentiating the three equilibrium conditions Eqs. (1.45), (1.51), and (1.52), with the results written as a matrix equation, we can analyze a change in the offshoring cost t as follows:

$$\begin{bmatrix} 0 & (w-w^*)\,\gamma'\left(\tilde{\delta}\right) & \gamma\left(\tilde{\delta}\right) \\ \Delta_1 & 0 & -e\tilde{\delta}\mu'_\gamma \\ \tilde{\delta}\mu'_\gamma & w^*\left[\gamma(\delta)-\gamma\left(\tilde{\delta}\right)\right]\gamma\left(\tilde{\delta}\right) & -\tilde{\delta}\mu''_\gamma \end{bmatrix} \begin{pmatrix} \frac{\gamma'(\delta)\delta d\ln\delta}{td\ln t} \\ \frac{\tilde{\delta}d\ln\tilde{\delta}}{w^*td\ln t} \\ \frac{wd\ln w}{w^*td\ln t} \end{pmatrix} = \begin{pmatrix} 1 \\ -\Delta_2 \\ -\tilde{\delta}\mu'_\gamma \end{pmatrix}. \tag{1.53}$$

The terms Δ_1 and Δ_2 are defined in Eq. (1.20) and are strictly positive. Using $\sigma^2_\gamma = \mu''_\gamma - \mu'^2_\gamma$, we can show that the determinant of the coefficient matrix Δ is positive:

$$\Delta = \left\{\left[\Delta_1 - e\tilde{\delta}\right]\tilde{\delta}\mu''_\gamma + e\tilde{\delta}^2\sigma^2_\gamma\right\}(w-w^*)\,\gamma'\left(\tilde{\delta}\right) + \Delta_1\gamma\left(\tilde{\delta}\right)^2 w^*\left[\gamma(\delta)-\gamma\left(\tilde{\delta}\right)\right] > 0. \tag{1.54}$$

In the following, we provide the solutions of the comparative statics exercise, which we use in the general equilibrium part of our model.

Effect on Domestic Wages:

$$\frac{wd\ln w}{w^* td\ln t} = \frac{1}{\Delta}\begin{vmatrix} 0 & (w-w^*)\,\gamma'\left(\tilde{\delta}\right) & 1 \\ \Delta_1 & 0 & -\Delta_2 \\ \tilde{\delta}\mu'_\gamma & w^*\left[\gamma(\delta)-\gamma\left(\tilde{\delta}\right)\right]\gamma\left(\tilde{\delta}\right) & -\tilde{\delta}\mu'_\gamma \end{vmatrix} \tag{1.55}$$

$$\frac{wd\ln w}{w^* td\ln t} = \frac{1}{\Delta}\left\{(w-w^*)\,\gamma'\left(\tilde{\delta}\right)e\left(\delta-\tilde{\delta}\right)\tilde{\delta}\mu'_\gamma + \Delta_1 w^*\left[\gamma(\delta)-\gamma\left(\tilde{\delta}\right)\right]\gamma\left(\tilde{\delta}\right)\right\} > 0 \tag{1.56}$$

Effect on Product Range:

$$\frac{\gamma'(\delta)\,\delta d\ln\delta}{td\ln t} = \frac{1}{\Delta}\begin{vmatrix} 1 & (w-w^*)\,\gamma'\left(\tilde{\delta}\right) & \gamma\left(\tilde{\delta}\right) \\ -\Delta_2 & 0 & -e\tilde{\delta}\mu'_\gamma \\ -\tilde{\delta}\mu'_\gamma & w^*\left[\gamma(\delta)-\gamma\left(\tilde{\delta}\right)\right]\gamma\left(\tilde{\delta}\right) & -\tilde{\delta}\mu''_\gamma \end{vmatrix} \tag{1.57}$$

$$\frac{\gamma'(\delta)\,\delta d\ln\delta}{td\ln t} = -\frac{1}{\Delta}\left(\begin{array}{c} \left\{\left[(1-e)+e\left(\delta-\tilde{\delta}\right)\right]\tilde{\delta}\mu''_\gamma + e\tilde{\delta}^2\sigma_\gamma^2\right\}(w-w^*)\,\gamma'\left(\tilde{\delta}\right) \\ +\left(\Delta_1\gamma\left(\tilde{\delta}\right)-e\tilde{\delta}\mu'_\gamma\right)w^*\left[\gamma(\delta)-\gamma\left(\tilde{\delta}\right)\right]\gamma\left(\tilde{\delta}\right) \end{array}\right) < 0 \tag{1.58}$$

Effect on Total Output: Totally differentiating Eq. (1.50) and using information from Eq. (1.56) yields

$$\frac{2b'\Delta_1 X}{w^* t}\frac{d\ln X}{d\ln t} = -\left(\delta-\tilde{\delta}\right) - \frac{\tilde{\delta}\mu'_\gamma}{\Delta}\left\{\begin{array}{c} (w-w^*)\,\gamma'\left(\tilde{\delta}\right)e\left(\delta-\tilde{\delta}\right)\tilde{\delta}\mu'_\gamma \\ +\Delta_1 w^*\left[\gamma(\delta)-\gamma\left(\tilde{\delta}\right)\right]\gamma\left(\tilde{\delta}\right) \end{array}\right\} < 0. \tag{1.59}$$

Effect on Cutoff Variety:

$$\frac{\tilde{\delta}d\ln\tilde{\delta}}{w^* td\ln t} = \frac{1}{\Delta}\begin{vmatrix} 0 & 1 & \gamma\left(\tilde{\delta}\right) \\ \Delta_1 & -\Delta_2 & -e\tilde{\delta}\mu'_\gamma \\ \tilde{\delta}\mu'_\gamma & -\tilde{\delta}\mu'_\gamma & -\tilde{\delta}\mu''_\gamma \end{vmatrix} \tag{1.60}$$

Using again $\sigma_\gamma^2 = \mu_\gamma'' - \mu_\gamma'^2$, we derive the following result:

$$\frac{d\ln\tilde{\delta}}{w^* t d\ln t} = \frac{1}{\Delta}\left(\Delta_1\mu_\gamma'' - e\left[\left(\delta - \tilde{\delta}\right)\gamma\left(\tilde{\delta}\right) + \tilde{\delta}\mu_\gamma'\right]\mu_\gamma'\right) \gtreqless 0. \tag{1.61}$$

1.5.4 Effects of an Exogenous Change in Domestic Wages

This section keeps offshoring costs t constant and considers responses of the system of endogenously determined variables in Eqs. (1.9), (1.13), (1.14), (1.16), and (1.19) to changes in the domestic wage rate. Totally differentiating this system of equations generates the following comparative statics results. It is apparent that with falling domestic wages total firm output will increase, i.e.

$$\frac{d\ln X}{d\ln w} = -\frac{w\widetilde{\delta}\mu_\gamma'}{2b'\Delta_1 X} < 0. \tag{1.62}$$

This effect gets larger the more domestic varieties benefit from falling wages, i.e. the higher is μ_γ', and the more domestic varieties are produced onshore, i.e. the higher is $\widetilde{\delta}$.

Changes in domestic factor prices clearly affect the cutoff variety $\widetilde{\delta}$ as it is determined by the equality of production costs on- and offshore. With Home becoming a more attractive production site, more varieties will be manufactured domestically, i.e.

$$\frac{d\ln\widetilde{\delta}}{d\ln w} = -\frac{w}{(w - w^*)}\frac{\gamma(\widetilde{\delta})}{\gamma'\left(\widetilde{\delta}\right)\widetilde{\delta}} < 0. \tag{1.63}$$

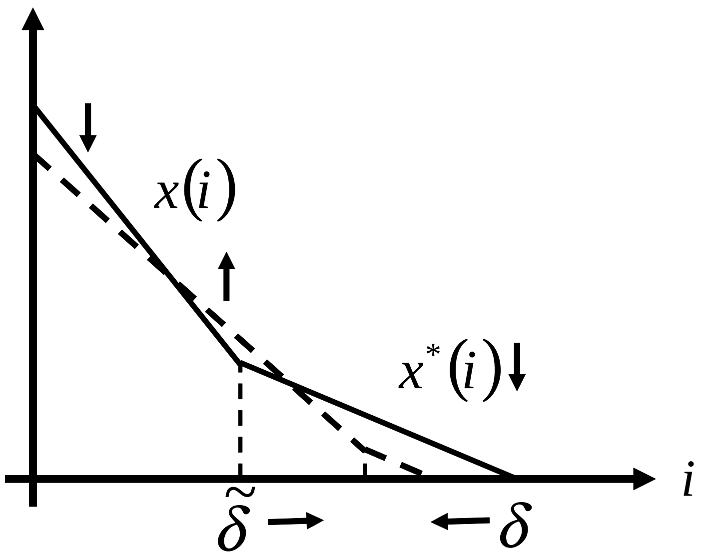
Akin to the previous result, we find that this effect gets stronger the more the cutoff variety benefits from falling wages in terms of a higher marginal labor requirement $\gamma(\widetilde{\delta})$. With varieties not being perfectly differentiated (i.e. $e > 0$), foreign scale gets crowded out

$$\frac{d\ln x^*(i)}{d\ln w} = \frac{w}{2b'(1-e)\,x^*(i)}\frac{e\widetilde{\delta}\mu_\gamma'}{\Delta_1} > 0, \tag{1.64}$$

and the product range decreases as marginal varieties undergo cannibalization

$$\frac{d\ln\delta}{d\ln w} = \frac{e\widetilde{\delta}w\mu_\gamma'}{\Delta_1 w^*\gamma'(\delta)\delta} > 0. \tag{1.65}$$

Figure 1.6: Exogenous Decrease in Domestic Wages



The cannibalization effect becomes stronger the more domestic production benefits from falling wages (i.e. the higher $\widetilde{\delta}$ and μ'_γ). Figure 1.6 illustrates all effects.

1.5.5 Numerical Example with a Linear Cost Function

In this section, we round down our analysis in general equilibrium with a numerical simulation, where we focus on the ambiguity of the effect of falling offshoring costs t on the cutoff variety $\widetilde{\delta}$. For specific parameter values and a linear cost function, Table 1.1 summarizes results for different degrees of product differentiation. Results once again underline the issue of cannibalization in this framework. We observe a falling total firm output X and a falling product range δ with rising substitutability between varieties (higher values of e). Referring to proposition 1.8 in the main body, it is important to mention that Table 1.1 shows a specific case where partial equilibrium results with respect to the cutoff variety $\widetilde{\delta}$ get reversed in general equilibrium, i.e. $\frac{d\widetilde{\delta}}{dt} < 0$. In this parameterization with an underlying linear cost function, we find more varieties being produced onshore with falling offshoring costs. As explained before, this result is due to the prevailing effect of falling domestic wages in comparison to the better prospects for offshoring.

Table 1.1: Numerical Example with a Linear Cost Function

Product differentiation e	w	X	$\widetilde{\delta}$	δ	$\frac{d\widetilde{\delta}}{dt}$	$\frac{d\delta}{dt}$
0.1	8.70	121.73	1.36	22.13	-0.688	-0.495
0.5	8.14	36.13	1.77	8.86	-1.081	-0.003
0.9	9.01	22.96	1.14	2.91	-0.370	-0.143

Notes: Parameter values are: $a' = 100$, $b' = 2$, $L^W = 20$, $w^* = 3.5$, and $t = 2.5$. For this calculation, we assume a linear cost function: $\gamma(i) = \gamma_0 + \gamma_1 i = 1 + 0.5i$.

Lemma 1.4 *By assuming a linear cost function within this framework, we can show that there is the possibility that an MPF produces even more varieties domestically when it faces better prospects for offshoring.*

Chapter 2

Product versus Process: Innovation Strategies of Multi-Product Firms

2.1 Introduction

Successful manufacturing firms continuously innovate to maintain their position in the market and to attend consumers' demand. Recent contributions in the international trade literature emphasize the importance of intra-firm adjustments through innovation in explaining welfare gains from trade liberalization, besides the well-established intra-industry gains from entry and exit of firms. This literature introduces innovation as a new dimension into the relationship between exporting and productivity: Better access to foreign markets leads to higher productivity through R&D in more sophisticated manufacturing technologies.[1] Consequently, innovation

[0]This chapter is based on joint work with Lisandra Flach. When working on this chapter, we have benefited from comments by Carsten Eckel, Jennifer Poole, and participants at the IO and Trade Seminar at the University of Munich and the Workshop "Internationale Wirtschaftsbeziehungen" in Goettingen 2014.

[1]Lileeva and Trefler (2010) as well as Bustos (2011) reveal that following a tariff cut firms increase their investments in technology. Lileeva and Trefler (2010) use tariff cuts associated with the US-Canadian free trade agreement and show that Canadian firms increased labor productivity and used more sophisticated manufacturing technologies. Furthermore, the access to a larger market induced firms to engage more in product innovation. For Argentinean firms, Bustos (2011) finds an increase in innovation expenditures by 0.20 to 0.28 log points following the average reduction

and productivity improvements within the firm account for a large fraction of productivity gains at the industry level.[2] Moreover, variety-loving consumers benefit not only from new products of entering firms but first and foremost from product innovation by incumbent firms.[3] Therefore, understanding innovation strategies and within-firm adjustments of multi-product firms (MPFs) is crucial for the analysis of aggregate productivity and variety gains.

MPFs account for the majority of trade flows and are omnipresent in all industries. In terms of innovation activities, their investments account for a large fraction of aggregate changes in industry-level productivity and product variety (Bernard et al. (2010), Broda and Weinstein (2010), Lileeva and Trefler (2010), Bustos (2011)). However, with the exception of Dhingra (2013) (which is discussed later in detail), innovation in trade models happens only in one dimension, whereas in reality firms face a trade-off between investments in cost reduction and product variety. This raises the question of how and why firms in different industries make their choices between different types of innovation, with different implications in terms of welfare gains within industries.

The contribution of this chapter is to investigate, theoretically and empirically, the innovation strategies of MPFs, focusing on within-firm adjustments. We evaluate a framework with demand and cost linkages in which firms face a trade-off between product and process innovation. Crucially, such linkages are only present in an MPF setting. Firms may decide to expand their product range or to lower production costs, and the net effect in terms of returns to innovation is a priori unclear.

In a simple model of MPFs, we show that returns to product and process innovation are industry-specific and uncover a mechanism related to the degree of product differentiation that explains this relation. On the one hand, by introducing new products firms internalize demand linkages, which may reduce demand for its own varieties. On the other hand, as a novel feature of our model, by investing in process

in Brazil's tariffs.

[2] Doraszelski and Jaumandreu (2013) show for Spanish firms that investments in R&D are the primary source of productivity growth. Within sectors, between 65 percent and 90 percent of productivity growth arises through intra-firm productivity enhancing activities.

[3] Recent evidence of US bar code data in Broda and Weinstein (2010) highlights the importance of this channel. They show that at a four-year period, 82 percent of product creation happens within existing firms. Therefore only 18 percent of total household expenditure is on products of entering firms.

innovation firms may internalize intra-firm spillover effects between production lines. To understand the role played by the degree of differentiation in this mechanism, consider two firms in sectors with different scope for product differentiation. A firm producing multiple products in a homogeneous industry has rather low returns from investing in new products as doing so may crowd out demand for its own products. This effect is known as the "cannibalization effect" in the literature. On the other hand, investments in process-optimizing technologies may generate a larger return, since the benefits from spillover effects across production lines are larger. With more similar production processes, the knowledge learned in the production process of more homogeneous products is applicable to a large fraction on the entire product portfolio. For firms in highly differentiated industries, the mechanism works exactly the other way round.

Our theoretical model builds on Eckel and Neary (2010) and Eckel et al. (2011). Each firm produces a bundle of products which are linked on the cost side by a flexible manufacturing technology. The latter captures the idea that - besides a core competence - MPFs can expand their portfolio with varieties that are less efficient in production.[4] However, our theory introduces several novel features. *First*, we explicitly allow for two types of R&D. Therefore, we assign fixed costs to additional products to model the decision on optimal scope closer to the notion of product innovation. *Second*, firms can invest in product-specific process innovation. Process innovation is costly and reflects economies of scale, such that firms invest more in optimizing technology of large-scale varieties close to their core competence. *Third*, another novel feature of our framework is to allow for spillover effects between the production processes within the firm. We relate the strength of these cost linkages to the degree of product differentiation in a sector. This occurs because products that are closer substitutes tend to have more similar production processes (in comparison to highly differentiated products).

Our framework has important implications for understanding how firms react to trade openness and to changes in market size. In particular, the model provides two main testable predictions. (1) We show that, following an increase in market size, firms invest more in innovation. As process innovation reflects economies of scale,

[4]The idea that firms possess a core competency is also featured in models with MPFs by Arkolakis and Muendler (2010), Qiu and Zhou (2013), and Mayer et al. (2014).

access to a larger market promotes technology upgrading. Furthermore, access to larger markets reduce the perceived costs of product innovation, which encourages MPFs to extend their product scope. (2) However, in our framework, demand and cost linkages related to the degree of product differentiation determine returns to innovation. We show that in highly differentiated industries, the cannibalization effect is lower and, therefore, firms invest more in product innovation. In homogeneous industries, firms internalize higher intra-firm spillover effects and invest more in process innovation.

The predictions from the model are tested using detailed firm-level data, which has two distinctive features. *First*, we can exploit detailed information on innovation investments by firms in the period 1998-2000. *Second*, the event of a major and unexpected exchange rate devaluation in January 1999 provides an important source of exogenous variation. The currency devaluation made Brazilian products more competitive at home and abroad and, therefore, the shock may be interpreted as an increase in market size. Moreover, we are interested in how firms in different industries reacted to the exchange rate shock, in order to test prediction (2) from the model. To tackle this issue empirically, we use information on different types of innovation combined with the degree of differentiation of the industry.

Our empirical results reveal that firms increased their innovation efforts in both product and process innovation following the exchange rate devaluation. However, detailed information on the degree of differentiation and on the types of innovation conducted by firms allows us to evaluate differential effects across industries. Using a continuous measure of the degree of differentiation in an industry, we show that firms in more differentiated industries invest more in product innovation, while firms in more homogeneous industries invest more in process innovation. Our results are robust to different measures of the degree of differentiation, hold for different estimation strategies (we estimate the incidence of innovation using probit, linear probability model, and seemingly unrelated regression), and remain stable when adding several control variables.

This chapter is closely related to the literature on MPFs in international trade that features a cannibalization effect.[5] Our theory builds on Eckel et al. (2011), who

[5] Eckel and Neary (2010) and Dhingra (2013) introduce cannibalization effects. However, this feature is not considered in many recent models of MPFs that assume monopolistic competition.

incorporate an endogenous investment in product quality in the framework by Eckel and Neary (2010). We abstract from investments in quality and instead focus on investments in product and process innovation. The paper that is closest in spirit to ours is Dhingra (2013), who also considers an innovation trade-off of MPFs. Dhingra (2013) proposes a model of MPFs with intra-brand cannibalization that induces a distinction between the returns to product and process innovation. Her framework explains how firms react to trade liberalization in terms of innovation investments. Following a trade liberalization, firms face higher competition from foreign firms and, therefore, reduce investments in product innovation to mitigate internal competition (cannibalization effect). On the other hand, firms increase investments in process innovation because of economies of scale. In contrast to her theoretical framework, we build a framework with demand and cost linkages to evaluate heterogeneous responses of firms in different industries. Moreover, using detailed firm-level data, we test the predictions from the model. In terms of the way we model innovation, the key differences between our analysis and that of Dhingra (2013) are that we (1) allow for flexible manufacturing and (2) introduce cost linkages related to the degree of differentiation that generate spillover effects within the firm. Therefore, our model is able to generate novel predictions regarding the two types of innovation depending on the degree of differentiation of the industry.

This chapter is also related to the literature emphasizing the complementary between market size and innovation behavior of firms that leads to gains from trade. Since innovation is costly, changes in market size tend to encourage firms to incur these costs because of scale effects. Models such as Grossman and Helpman (1991) investigate the gains from trade arising from innovation investments in a setting with homogeneous firms. At the firm-level, several papers have investigated the relation between changes in market size and innovation. Lileeva and Trefler (2010) investigate theoretically and empirically how changes in market size encouraged firms to innovate. Using responses of Canadian plants to the elimination of U.S. tariffs, they find that plants more induced by the tariff cuts increase more their investments in innovation. Yeaple (2005), Verhoogen (2008), Bustos (2011), and Aw et al. (2011) assess further channels that relate market size with firm-level innovation and within-firm adjustments.

One exception is the model proposed by Feenstra and Ma (2008).

2.2 The Model

Our theory draws on a simple model of MPFs that choose their optimal spending on product and process innovation. Both types of innovation are costly and, therefore, firms weight the returns to innovation against the costs. The returns to innovation are in the focus of this chapter and constitute the main testable predictions from the model. First, we show that the returns to product and process innovation are higher in a larger market. Second, we point out that firms in sectors with homogeneous products focus on optimizing production processes while firms in more differentiated industries concentrate on innovating new products. These innovation patterns follow from demand and cost linkages, both related to the degree of product differentiation in a sector. Since these linkages determine the returns to innovation, we will introduce them at the very outset.

We begin with a detailed analysis of consumer behavior and the underlying preference structure in section 2.2.1. In this part, we show how the demand linkages enter our framework and relate them to the degree of product differentiation in a sector. In section 2.2.2, we present the firm side of the model. We start with the production cost function, which is characterized by flexible manufacturing. Moreover, firms can undertake investments in process innovation to reduce production costs of a product, which may generate spillovers between production lines. We refer to this feature as a cost linkage and argue that its strength decreases in the degree of product differentiation. Firms consider both linkages when maximizing their profits. Finally, section 2.2.3 derives the equilibrium of the model and establishes the main testable predictions from the theory.

2.2.1 Consumer Behavior: Preferences and Demand

Our economy consists of L consumers who maximize their utility over the consumption of a homogeneous and a differentiated good. To be more specific, we assume that consumers buy a set Ω of goods out of a potential set $\widetilde{\Omega}$ of the differentiated product. Our specification of preferences follows Eckel et al. (2011), though we add an additional numeraire good and assume a quasi-linear utility in the following form:[6]

$$U = q_0 + u_1, \tag{2.1}$$

where q_0 is the consumption of the homogeneous good. We conduct our analysis in partial equilibrium where the outside good absorbs any income effects. Utility over the differentiated variety is defined in a standard quadratic function as follows

$$u_1 = aQ - \frac{1}{2}b\left[(1-e)\int_{i\in\widetilde{\Omega}} q(i)^2 di + eQ^2\right], \tag{2.2}$$

where a and b represent non-negative preference parameters. In this specification, $q\,(i)$ denotes per variety consumption and $Q \equiv \int_{i\in\widetilde{\Omega}} q(i)di$ stands for total consumption of the representative consumer. The parameter e plays a very important role in our model and describes the degree of product differentiation. We assume that e lies strictly between zero and one and define the parameter as an inverse measure for product differentiation. This means that lower values of e imply more differentiated and hence less substitutable products. Throughout the analysis, we will distinguish industries along the degree of product differentiation. We simply refer to a *homogeneous* industry as an industry with a relatively high value of e. Accordingly, a *differentiated* industry means an industry with a value of e close to zero. A detailed discussion of the role of the parameter e in our model will follow later on in the analysis.

Consumers maximize utility subject to the budget constraint $q_0 + \int_{i\in\widetilde{\Omega}} p(i)q(i)di = I$. Hence, individual income I is spent on consumption of the outside good and the potential basket $\widetilde{\Omega}$ of the differentiated good. $p\,(i)$ is the price of variety i and the numeraire good is sold at a price $p_0 = 1$. We assume that consumers demand a positive amount of the outside good $q_0 > 0$ to ensure consumption of the differentiated good. Maximizing utility and aggregating individual demand functions yields a linear market demand:[7]

$$p(i) = a - b'\left[(1-e)x(i) + eX\right]. \tag{2.3}$$

[6] The preferences in Eckel et al. (2011) capture an additional component adressing the utility which accrues from consuming goods of higher quality.

[7] Given the quasi-linear upper-tier utility, there is no income effect, thereby implying that the marginal utility of income $\lambda = 1$.

We define $\Omega \subset \widetilde{\Omega}$ as the subset of varieties which is actually consumed. $x(i)$ describes the market demand for variety i and consists of the aggregated demand of all consumers $Lq(i)$ for that specific variety. $X \equiv \int_{i\in\Omega} x(i)di$ is the total volume of consumption of all differentiated goods. Furthermore, a describes the demand intercept and $b' \equiv \frac{b}{L}$ defines an inverse measure for the size of the market. Direct demand of variety i is given by

$$x(i) = \frac{a}{b'(1-e+e\delta)} - \frac{1}{b'(1-e)}p(i) + \frac{e\delta}{b'(1-e+e\delta)(1-e)}\overline{p}, \tag{2.4}$$

where δ describes the measure of consumed varieties in Ω. The average price of differentiated varieties in the economy is given by $\overline{p} = 1/\delta \int_{i\in\Omega} p(i)\,di$.

As demand linkages will play a crucial role in our model, we conclude this section by analyzing how the degree of product differentiation affects the cross elasticity between any two varieties and the price elasticity of demand. The cross elasticity of variety i with respect to variety j is given by $\varepsilon_{i,j} \equiv |(\partial x(i)/\partial x(j))(x(j)/x(i))| = ex(j)/(1-e)x(i)$. It is straightforward to see that $\varepsilon_{i,j}$ is higher in more homogeneous sectors. For a firm this means: The closer is the substitutability between its varieties, the more does the output of any additional variety reduce the demand for the other products within its portfolio (i.e. the stronger are the demand linkages in a sector).

In addition to the cross elasticities, we also compute the price elasticity of demand to relate e to our empirical measure of differentiation. The empirical part of this chapter uses the Khandelwal (2010) classification as the preferred measure for product differentiation. This measure is created by evaluating changes in prices conditional on market shares: A product is classified as more differentiated if the firm can increase prices without losing market shares. To connect this to our theoretical model, we compute the price elasticity of demand and show how it responds to a change in the degree of differentiation in a sector. Given the linear demand system in Eq. (2.3), there exists an upper bound of the price, where demand $x(i)$ is just driven to zero:

$$p^{\max} \equiv \frac{(1-e)a + e\delta\overline{p}}{(1-e+e\delta)}. \tag{2.5}$$

Following Melitz and Ottaviano (2008), we express the price elasticity of demand as

$$\varepsilon_i \equiv \left| \frac{\partial x(i)}{\partial p(i)} \frac{p(i)}{x(i)} \right| = \frac{p(i)}{(p^{\max} - p(i))}, \tag{2.6}$$

by combining Eqs. (2.4) and (2.5). Inspecting the latter expression clarifies the role of the degree of product differentiation e in determining the demand linkages in our model. It can easily be shown that, ceteris paribus, the choke price $p^{\max}$ decreases and, therefore, the price elasticity ε_i increases when products become more homogeneous.

$$\frac{\partial p^{\max}}{\partial e} \mid_{\overline{p},\delta=const} = -\frac{\delta(a-\overline{p})}{(1-e+e\delta)^2} < 0. \tag{2.7}$$

This implies that the parameter e in our theoretical model is closely related to the Khandelwal (2010) measure of differentiation which we use in the empirical part of our analysis.

2.2.2 Firm Behavior: Optimal Product and Process Innovation

In this section, we consider technology and optimal firm behavior. To keep the analysis as simple as possible, we rely on the monopoly case (since we focus on intra-firm adjustments, competition between firms plays only a second-order role). We construct a theoretical model in which MPFs optimally choose between two types of investment. Firstly, firms invest in new product lines and thereby extend their product portfolio. Secondly, firms may decide for each of their products how much to invest in the production technology. Both types of investment depend on the degree of product differentiation through the demand and cost linkages taken into account by a firm. In the previous section, we have already introduced the demand linkages into our model. We argue that the demand linkages in particular determine the returns to product innovation. While deciding on the optimal number of products, the firm considers the negative impact of the marginal good on the demand for the rest of its products. Hence, the more similar are the products within the portfolio, the stronger will be the cannibalization effect of the marginal variety. Consequently, we show that the optimal product range will be smaller in a homogeneous sector.

As a novel feature of our model, we introduce cost linkages and relate them to the degree of product differentiation. In particular, the strength of the cost-linkages determines the returns to process innovation in our model. Firms may decide for each product how much to invest. However, we argue that there are intra-firm spillover effects between the varieties. This means that a firm can use parts of the process R&D of one product for other products in its portfolio. To which extent product-specific R&D is applicable to other processes depends on the similarity of production processes and, therefore, on the degree of product differentiation. Thus, firms in homogeneous sectors will invest more in process innovation as they can internalize more spillovers between production lines.

Production Technology Production is characterized by flexible manufacturing. We follow Eckel and Neary (2010) and assume that firms have a core competence $i = 0$, which denotes the product where the firm is most efficient in production. Besides the core variety, an MPF can produce additional varieties with rising marginal costs. Production costs for variety i without investments are given by $c(i) = c + c_1 i$. For the sake of simplicity, we assume a linear cost function, though this is not required to derive our results.

Firms can reduce production costs through variety specific process innovation. Furthermore, we allow for investment spillovers between products. To reduce production costs of variety i, a firm undertakes process innovation $k(i)$ which reduces production costs at a diminishing rate. The variety specific costs savings from innovation are given by $2k(i)^{0.5}$. As mentioned earlier, part of the process optimization of one variety is applicable to all other varieties, which implies that production of variety i benefits from all investments undertaken on all the other products $K_{-i} \equiv \int_{\Omega \setminus i} k(i)^{0.5}\, di$. The degree to which knowledge is applicable to other products depends on the spillover parameter $\theta(e) \in (0;1)$. The spillover parameter θ depends on the degree of product differentiation e because of the assumption that spillovers are larger in a more homogeneous sector. We will define a functional form for this parameter later on in the analysis.

Considering these aspects, production costs of variety i are given by:

$$c(i) = c + c_1 i - \left(2k(i)^{0.5} + 2\theta(e) K_{-i}\right). \qquad (2.8)$$

This can be rearranged to

$$c(i) = c + c_1 i - \left(2\left(1-\theta(e)\right)k(i)^{0.5} + 2\theta(e)K\right), \tag{2.9}$$

where in analogy to X, $K = \int_0^\delta k(i)^{0.5}\,di$ denotes total investment in process innovation.

Profit Maximization In our setup, an MPF simultaneously chooses optimal scale $x(i)$ and process innovation $k(i)$ per product as well as optimal product scope δ. Process innovation is carried out at a rate r_k and product innovation requires building a new production line at a rate r_δ. Total profits are given by:

$$\pi = \int_0^\delta \left[p(i) - c - c_1 i + 2\left(1-\theta(e)\right)k(i)^{0.5} + 2\theta(e)K\right]x(i)di - \int_0^\delta r_k k(i)\,di - \delta r_\delta. \tag{2.10}$$

Optimal Scale: Maximizing profits in Eq. (2.10) with respect to scale $x(i)$ implies the following first-order condition:[8]

$$\frac{\partial\pi}{\partial x(i)} = p(i) - c - c_1 i + 2\left(1-\theta(e)\right)k(i)^{0.5} + 2\theta(e)K - b'(1-e)x(i) - b'eX = 0. \tag{2.11}$$

Using the inverse demand in Eq. (2.3) and solving for $x(i)$ yields optimal scale of variety i:

$$x(i) = \frac{a - c - c_1 i + 2\left(1-\theta(e)\right)k(i)^{0.5} + 2\theta(e)K - 2b'eX}{2b'(1-e)}. \tag{2.12}$$

Furthermore, we derive total firm scale X by integrating over $x(i)$ in Eq. (2.12):

$$X = \frac{\delta\left(a - c - c_1\frac{\delta}{2}\right) + 2\left(1-\theta(e)+\theta(e)\delta\right)K}{2b'(1-e+e\delta)}. \tag{2.13}$$

Inspection of Eq. (2.12) reveals the two opposing linkage effects arising from the degree of product differentiation in a sector. On the one hand, there is a demand

[8]The second-order condition is negative: $\frac{\partial^2\pi}{\partial x(i)^2} = -2b' < 0$.

linkage (cannibalization) of total firm's scale X on the output of a single variety

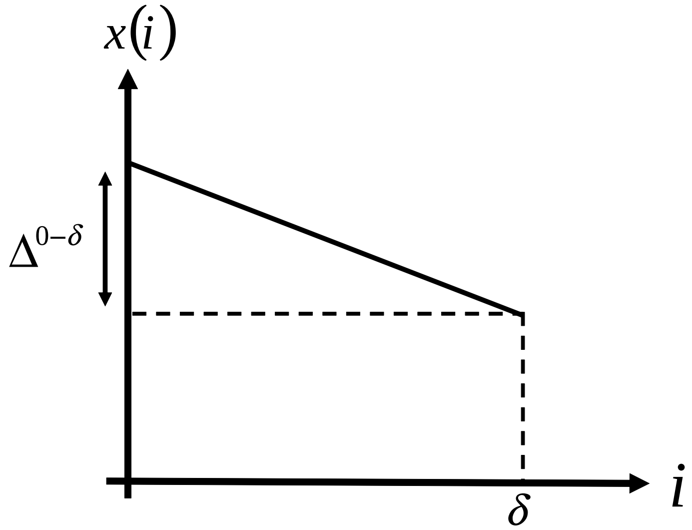
$$\frac{\partial x\left(i\right)}{\partial X}=-\frac{e}{1-e}<0, \tag{2.14}$$

whereby the negative impact increases in e. On the other hand, with rising values of e the cost linkages (spillovers) from other varieties become more prominent:

$$\frac{\partial x\left(i\right)}{\partial K}=\frac{\theta\left(e\right)}{b'\left(1-e\right)}>0. \tag{2.15}$$

As a result of the underlying cost structure with flexible manufacturing, optimal scale of the core product is the largest, and output per variety diminishes with distance to the core product. We illustrate the output scheme in Figure 2.1, where $\Delta^{0-\delta}$ indicates the difference in scale between the core and marginal product in the portfolio. The exact mathematical expression for $\Delta^{0-\delta}$ is determined later on in the analysis.

Figure 2.1: Output Schedule



Substituting optimal scale in Eq. (2.12) into the inverse demand gives the optimal pricing schedule, with the lowest price charged for the core product:

$$p(i)=\frac{1}{2}\left[a+c+c_1 i-2\left(1-\theta\left(e\right)\right)k\left(i\right)^{0.5}-2\theta\left(e\right)K\right]. \tag{2.16}$$

The latter explains why the output of the core competency is sold at the highest scale. Finally, the price-cost margin for variety i is given by:

$$p(i) - c(i) = \frac{a - c - c_1 i + 2(1 - \theta(e)) k(i)^{0.5} + 2\theta(e) K}{2}. \tag{2.17}$$

Optimal Process Innovation: Firms can invest in cost-reducing process innovation for each product in the portfolio. At the optimum, direct savings through lower production costs plus indirect savings from spillovers on other products are equal to the rate of innovation costs r_k:

$$\frac{\partial \pi}{\partial k(i)} = (1 - \theta(e)) k(i)^{-0.5} x(i) + \theta(e) k(i)^{-0.5} X - r_k = 0. \tag{2.18}$$

Solving for optimal investments in variety i yields:[9]

$$k(i) = \left(\frac{(1 - \theta(e)) x(i) + \theta(e) X}{r_k} \right)^2. \tag{2.19}$$

Eq. (2.19) shows that optimal investment reflects economies of scale through both per variety output $x(i)$ and total firm output X. Given that the output of the core variety is the highest, a firm will put most effort in optimizing the production process of this variety.[10] However, the first-order condition in Eq. (2.19) implies that the larger the spillovers $\theta(e)$ on other products within the firm, the more equally a firm spreads investments across products. In the extreme case of $\theta(e) = 1$, investment levels are the same across products.

Lemma 2.1 *Firms concentrate investments in process innovation on their core competencies, since process innovation reflects economies of scale. However, the investment levels across varieties become more similar in more homogeneous sectors due to higher spillover effects.*

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[9] The second-order condition is given by: $\frac{\partial^2 \pi}{\partial k(i)^2} = -0.5 \left(k(i)^{-1.5} (1 - \theta(e)) x(i) + \theta(e) X \right) < 0$, and is negative as required.

[10] Evidence for economies of scale at the product level can be found in Lileeva and Trefler (2010).

Finally, we substitute Eq. (2.12) into Eq. (2.19) and integrate over the expression. This gives total firm investment in process innovation

$$K \equiv \int_0^{\delta} k(i)^{0.5}\, di = \frac{(1-\theta(e))\left(\delta a - \delta c - c_1\frac{\delta^2}{2}\right) + 2b'(\theta(e) - e)\delta X}{2\left(b' r_k (1-e) - (1-\theta(e))(1-\theta(e) + \theta(e)\delta)\right)}. \tag{2.20}$$

Optimal Product Innovation: Choosing optimal product scope means balancing the benefits of the marginal variety against the innovation costs. The first-order condition for scope is given by:

$$\frac{\partial \pi}{\partial \delta} = [p(\delta) - c(\delta)]\, x(\delta) + \left(-b' e x(\delta) + 2\theta(e)\, k(\delta)^{0.5}\right) X - r_k k(\delta) - r_\delta = 0, \tag{2.21}$$

where $c(\delta) = c + c_1\delta - 2(1-\theta(e))\, k(\delta)^{0.5} - 2\theta(e)\, K$. In our framework with both cost and demand linkages, the marginal benefit of a product is determined by the negative externality on all other products (cannibalization) and the positive externality (spillovers in process innovation).[11]

$$\underbrace{[p(\delta) - c(\delta)]\, x(\delta)}_{\text{Revenue}} + \{\underbrace{(-b' e x(\delta))}_{\text{Cannibalization}} + \underbrace{\left(2\theta(e)\, k(\delta)^{0.5}\right)}_{\text{Spillover}}\} X = \underbrace{r_\delta + r_k k(\delta)}_{\text{Inn. Costs}} \tag{2.22}$$

In the decision to optimize the product range, an MPF takes into account that an additional product lowers the prices consumers are willing to pay for all other products. This aspect is captured by the term "Cannibalization" in Eq. (2.22). The term "Spillover" in Eq. (2.22) reflects the fact that there are spillovers from the marginal product on all other varieties. Hence, at this point it seems plausible to make a restriction on the parameter values which determines the net effect of the two linkages.

Condition 2.1 *In Eq. (2.22), the net impact of the marginal variety on all other varieties is determined by the strength of the two linkages in our model. It is plausible to assume that the net impact of the marginal product on all varieties is negative.*

[11] The second-order condition is given by: $\frac{\partial^2 \pi}{\partial \delta^2} = \left[-c_1 - 2\left(b' e x(\delta) - 2\theta(e)\, k(\delta)^{0.5}\right)\right] x(\delta) < 0$. To see that this condition is negative as required, consider Condition 2.1.

Therefore, we restrict the parameters as follows:

$$b'r_k > \frac{2\theta(e)\left((1-\theta(e))\,x(\delta)+\theta(e)\,X\right)}{ex(\delta)}. \tag{2.23}$$

This condition implies that the perceived cost of process innovation may not be too low. We refer to $b'r_k$ as the perceived costs of process innovation, as this term relates the market size to the innovation costs. Therefore, the perceived costs can fall (1) if r_k decreases or (2) if the market size L increases (recall that: $b' \equiv \frac{b}{L}$). We argue that this restriction of parameters ensures realistic properties within our framework. If process innovation would be too "cheap", firms would increase product scope only to benefit from spillovers from the investment in the marginal variety. The latter does not seem to be a realistic optimal firm behavior.

In the following, we express a firm's optimal scope in terms of scale of the marginal product $x(\delta)$. To do so, we substitute the output of the marginal variety from Eq. (2.12) and its respective price-cost margin from Eq. (2.17) into the first-order condition for scope (2.21):

$$x(\delta) = \sqrt{\frac{r_k k(\delta) + r_\delta - 2\theta(e)\,k(\delta)^{0.5}\,X}{b'(1-e)}}. \tag{2.24}$$

Considering again Figure 2.1, the latter expression can be interpreted as follows: The lower is the output of the marginal variety δ, the larger is the product range offered by the firm.

To provide some further insights into our model, we combine the first-order conditions for scale and scope in Eqs. (2.12) and (2.24), to derive an alternative expression for optimal scale:

$$x(i) = \frac{c_1(\delta - i) + 2(1-\theta(e))\left(k(i)^{0.5} - k(\delta)^{0.5}\right)}{2b'(1-e)} + \sqrt{\frac{r_k k(\delta) + r_\delta - 2\theta(e)\,k(\delta)^{0.5}\,X}{b'(1-e)}}. \tag{2.25}$$

It is straightforward to see that this expression boils down to Eq. (2.24) by setting $i = \delta$ for the marginal variety. Furthermore, we can use this expression to calculate the difference in scale of the core ($i = 0$) versus the marginal variety δ, illustrated in Figure 2.1:

$$\Delta^{0-\delta} = \frac{c_1 \delta}{2\left(b'(1-e) - \frac{(1-\theta(e))^2}{r_k}\right)}. \tag{2.26}$$

Since the underlying technology is flexible manufacturing, the difference in output increases in the product range δ. The larger is the distance to the core product, the lower will be the efficiency of the marginal product. The latter effect is magnified for higher values of c_1, as this variable determines how much marginal costs increase with rising distance to the core product. Moreover, $\Delta^{0-\delta}$ decreases in the strength of the spillovers $\theta(e)$. As stated in Lemma 2.1, firms concentrate their investment in process R&D on the core varieties. However, if spillover effects are large, the marginal varieties benefit more from the investments in the high-scale core varieties.

Lemma 2.2 *The difference in scale between the core and the marginal variety is determined by the difference in production costs of the two varieties. The productivity of the marginal product falls with distance to the core product and rises in the degree of spillovers.*

2.2.3 Comparative Statics

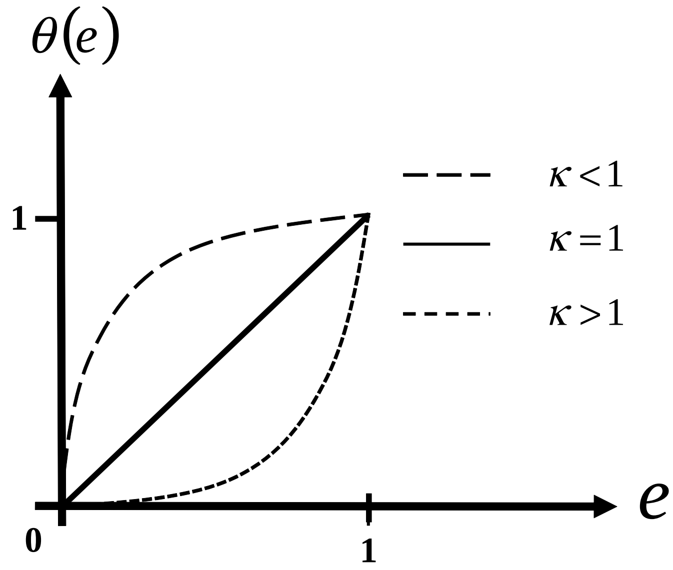
In the previous section, we established the baseline theoretical framework. In the next step, we derive the main predictions that we test in the empirical section. To start with, we analyze the effects of an increase in the market size L (lower values of b') on optimal investment levels. Furthermore, we investigate optimal investment strategies in sectors with different degrees of product differentiation. To derive our results, we follow the solution path in Eckel and Neary (2010), and express the equilibrium equations in terms of X and δ only. Moreover, as already mentioned, we define a functional form for the spillover parameter $\theta(e)$:

$$\theta(e) = e^{\kappa}. \tag{2.27}$$

Figure 2.2 illustrates this functional form and the role of κ in determining the strength of spillovers.

Since $e \in [0, 1]$, lower values of κ translate into a stronger spillover effect. In the extreme case of $\kappa = 0$, the total investment in one variety is applicable on all

Figure 2.2: Spillover Parameter



varieties within the firm. Obviously, we derive the same result in an industry with no product differentiation (i.e. $e = 1$). Letting κ grow large decreases the importance of spillovers within the firm.

Equilibrium In this section, we derive the equilibrium equations of the model applying the functional form of spillovers in Eq. (2.27). Combining Eqs. (2.13) and (2.20), we derive total firm scale as:

$$X = \frac{\delta\left(a - c - c_1\frac{\delta}{2}\right)}{2\left(b'(1-e+e\delta) - \frac{(1-e^{\kappa}+e^{\kappa}\delta)^2}{r_k}\right)}. \tag{2.28}$$

The term $\frac{(1-e^{\kappa}+e^{\kappa}\delta)^2}{r_k}$ reflects cost-savings from process innovation, which induces a firm to increase total firm scale X. Clearly, the strength of the latter effect is mitigated by the costs for process innovation r_k. Plugging Eq. (2.28) back into Eq. (2.20) yields total process innovation as:

$$K = \frac{(1-e^{\kappa}+e^{\kappa}\delta)}{r_k}X. \tag{2.29}$$

The parameter κ determines the strength of spillovers, where total process innovation is the largest for $\kappa = 0$. Inspecting Eqs. (2.28) and (2.29) in detail reveals that investments in process innovation decrease with rising levels of κ, i.e. $\frac{\partial K}{\partial \kappa} < 0$. Furthermore, process innovation K reflects economies of scale as it depends on total firm scale X. Using information from Eqs. (2.19), (2.28), and (2.29) together with Eq. (2.12), we can express optimal scale per variety as:

$$x(i) = \frac{a - c - c_1 i - 2\left(b'e - \frac{e^{\kappa}(2(1-e^{\kappa})+e^{\kappa}\delta)}{r_k}\right)X}{2\left(b'(1-e) - \frac{(1-e^{\kappa})^2}{r_k}\right)}. \tag{2.30}$$

Within our framework, we have two opposing effects of total scale X on per variety output. On the one hand, rising total output induces the firm to invest more in process innovation, which increases per variety output. On the other hand, rising total scale intensifies cannibalization within the portfolio. The latter effect reduces per variety output. However, Condition 2.1 stated in Eq. (2.23) guarantees that the spillover effect cannot dominate the cannibalization effect, i.e. $\frac{\partial x(i)}{\partial X} < 0$.

Finally, substituting from Eq. (2.19) into Eq. (2.24), we express the first-order condition for scope as:

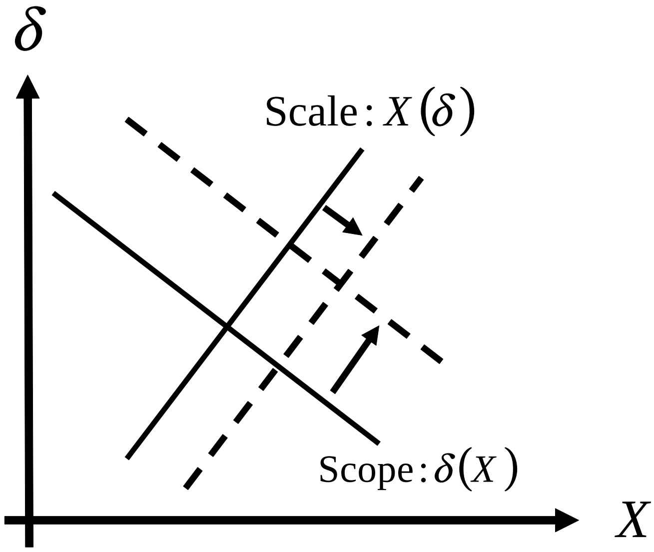
$$x(\delta) = \sqrt{\frac{r_\delta - \frac{(e^{\kappa}X)^2}{r_k}}{\left(b'(1-e) - \frac{(1-e^{\kappa})^2}{r_k}\right)}}. \tag{2.31}$$

The formal derivation of this expression is presented in the Appendix. Eq. (2.31) implicitly defines product scope δ in terms of the output of the marginal variety. Solving for δ gives the explicit expression for product scope:

$$\delta = \frac{a - c - 2\sqrt{\left(b'(1-e) - \frac{(1-e^{\kappa})^2}{r_k}\right)\left(r_\delta - \frac{e^{2\kappa}X^2}{r_k}\right)} - 2\left(b'e - \frac{2e^{\kappa}(1-e^{\kappa})}{r_k}\right)X}{\left(c_1 - \frac{2e^{2\kappa}X}{r_k}\right)}. \tag{2.32}$$

Eqs. (2.31) and (2.32) reveal that higher costs for product innovation r_δ decrease the optimal product range. The latter implies a higher output of the marginal variety δ (see Eq. (2.31)). Referring to Figure 2.1, this characterizes a variety closer

Figure 2.3: Equilibrium



to the firm's core competence. Inspecting the term $2\sqrt{\cdot}$ in Eq. (2.32) reveals the multiplicative structure of the inverse measure for market size ($b' \equiv \frac{b}{L}$) and the cost for product innovation r_δ. This structure translates an increase in the market size L into lower perceived costs of product innovation for the firm.

Inspecting the previous equations indicates that the equilibrium in our model can be characterized in terms of two endogenous variables: δ and X. In Figure 2.3, Eq. (2.28) is labeled by "Scale: $X(\delta)$" and describes a positive relationship between total firm output X and scope δ. Through adding additional products, an MPF can increase its total output. Eq. (2.32) establishes a negative relationship between X and δ. The downward-sloping curve "Scope: $\delta(X)$" illustrates that rising firm output intensifies the cannibalization effect of the marginal variety. Therefore, an MPF reduces its product scope when its total output increases.In the intersection of both curves in Figure 2.3, the two equilibrium conditions for scale and scope are satisfied.[12] Once we have determined the equilibrium values of δ and X, we compute the equilibrium value of process innovation K. In the next step, we derive the main testable predictions from the model.

[12] A proof that the two curves intersect is provided in the Appendix. We show that the determinant of the coefficient matrix is always positive. This ensures that the equilibrium is unique and stable.

The Effects of a Larger Market Size We are interested in the effects of globalization on product and process innovation. We follow Krugman (1979) and interpret globalization as an increase in the number of consumers L. As we analyze the behavior of a single MPF, we neglect the competition effect of globalization. This modeling choice is motivated by the nature of our empirical analysis, where we investigate the effect of a devaluation of the Brazilian *real*. For Brazilian exporters, a devaluation means improved access to foreign markets since products become cheaper. Therefore, Brazilian firms can gain foreign market shares without losing domestic market shares.

An increase in the market size L reduces the slope b' of the demand function in Eq. (2.3). In the Appendix, we derive the total derivatives of the equilibrium conditions in terms of scale X (Eq. (2.28)) and scope δ (Eq. (2.32)), which lead to the following results.

We show that increases in the market size lead to higher total firm output X. Three different intra-firm adjustments lead to this result. The first adjustment comes from the increased demand in the larger market. The second and third adjustments come from the impact of product and process innovation on total firm scale X. We show that despite cannibalization is intensified through the larger X, a firm will invest in new products in a larger market. In Figure 2.3, both curves "Scale: $X(\delta)$" and "Scope: $\delta(X)$" are shifted to the right, though "Scope: $\delta(X)$" shifts more. The cannibalization effect of increasing firm scale X on scope δ can be visualized by comparing the product range before and after the shift of "Scale: $X(\delta)$". Technically the increase in product scope is caused by the fact that in Eq. (2.32) the costs for product innovation r_δ enter multiplied by the parameter b'. As explained earlier in the text, a larger market size reduces the perceived innovation costs for the firm. Finally, we analyze the impact of the market size on process innovation K. As discussed earlier, process innovation is subject to economies of scale as in a larger market innovation costs can be spread over more units. From inspection of Eq. (2.29), we see that the rise in δ and X causes more spending in process innovation. Captured by the term $\frac{(1-e^{\kappa}+e^{\kappa}\delta)^2}{r_k}$ in Eq. (2.28), the process innovation effect contributes to the rise in firm scale X. We summarize the market size effect on optimal firm behavior in the following proposition and test these results in the empirical section.

Proposition 2.1 *A larger market size L increases total scale X and induces firms to invest more in both product δ and process innovation K, i.e.*

$$\frac{d\ln X}{d\ln L} > 0,\ \frac{d\ln \delta}{d\ln L} > 0,\ \textit{and}\ \frac{d\ln K}{d\ln L} > 0. \tag{2.33}$$

The mathematical derivation of these results is presented in the Appendix. Furthermore, we show the effects of a change in the demand intercept a on the optimal behavior of the firm. The latter comparative static yields qualitatively the same results.

Sectors with Different Scope for Product Differentiation We derive a second testable prediction of our model with respect to the degree of product differentiation in a sector. A simple comparison between brick production and the automotive sector makes it clear that there is a lot more scope for differentiation in the latter sector. We argue that the degree of differentiation is crucial in explaining the innovation behavior of firms. Recall, that degree of differentiation determines the strength of the two linkages within our framework. A low degree of differentiation (high e) causes high cannibalization and high spillover effects and, therefore, promotes process innovation. One can think again of our example of an MPF producing bricks that are slightly differentiated. It is plausible to assume that a large fraction of the investment in the production line of one specific brick is applicable to the production of all other bricks produced by the same firm. However, introducing one further brick will have a strong cannibalizing impact on the initial portfolio. Differentiating Eq. (2.29) with respect to the degree of product differentiation e keeping firm size fixed confirms our intuition:

$$\frac{\partial \ln K}{\partial \ln e} = \frac{\kappa e^{\kappa}\left(\delta - 1\right)}{\left(1 - e^{\kappa} + e^{\kappa}\delta\right)} > 0. \tag{2.34}$$

Let us now assume the other extreme case of a highly differentiated industry, in our example the automotive sector. Assuming that cars are more differentiated than bricks, optimizing the production process for one specific car will have positive but lower spillovers on the other cars in comparison to the case of (more homogeneous) bricks. The more differentiated two cars are, the lower will be the number of identical parts used in production and, therefore, the lower will be the spillovers in production. However, for a firm producing multiple cars, the negative externality of adding an additional car declines the higher is the degree of differentiation (i.e. the lower is the cannibalization effect). Again, we hold firm size fixed and differentiate Eq. (2.32) with respect to the degree of product differentiation e. There are two opposing channels at work when considering the effect of the degree of product differentiation on the product range δ. On the one hand, the marginal product cannibalizes, on the other hand, all initial products benefit from process-spillovers from the marginal product. Differentiating Eq. (2.32) with respect to e leads to a cumbersome expression, which is presented in the Appendix. Here we show the solution for the case of the strongest spillover effects. The following derivative reveals that even in this case the cannibalization effect dominates, which confirms our intuition.

$$\lim_{\kappa\to 0}\frac{\partial\ln\delta}{\partial\ln e}=-\frac{b'e\left(2X-x\left(\delta\right)\right)}{\left(c_1-\frac{2X}{r_k}\right)\delta}<0 \tag{2.35}$$

The derivation of this expression and further discussion are presented in the Appendix.

We summarize the effect of the degree of product differentiation on optimal innovation behavior in the following proposition and test the results in the empirical part.

Proposition 2.2 *Conditional on firm size, firms in sectors with a large (low) scope for product differentiation will invest more in product (process) innovation. This behavior is caused by the lower (stronger) demand- and lower (stronger) cost-linkages in a differentiated (homogeneous) sector.*

2.3 Data

We test the main predictions of the model using Brazilian firm-level data for the period 1998-2000. Firm-level data are matched using the unique firm tax number and come from two main sources: (i) SECEX (Foreign Trade Secretariat), which provides information on the universe of products exported by Brazilian firms and (ii) Innovation survey from PINTEC (Brazilian Firm Industrial Innovation Survey).

We combine firm-level data with industry-level data to investigate how different industries react to a trade shock in terms of their investments in innovation.
A distinctive feature of the data is the availability of highly detailed information on firm-level innovation investments, including several dimensions of product and process innovation. A further distinctive feature of the data is the event of a major and largely unexpected exchange rate shock in the period under analysis. The devaluation made Brazilian products more competitive in both domestic and foreign markets and, therefore, increased incentives for firms to innovate (due to scale effects). However, firms react in different ways to the trade shock depending on the degree of product differentiation of the industry: While more homogeneous industries have higher incentives to invest more in process innovation because of spillover effects, differentiated industries have higher incentives to invest in product innovation because of lower cannibalization across products. To tackle this issue, we use information on different types of innovation combined with the degree of product differentiation of the industry.

2.3.1 Innovation Variables

The innovation survey provides detailed information on innovation investments of 3,070 manufacturing exporters for which we can exploit time-varying information.[13]
The main questions used in our study for product and process innovation are: 1. Did the firm introduce a new product in the period? (*product innovation*) and 2. Did the firm introduce new production processes in the period? (*process innovation*). For changes in product, we create a variable $\Delta Product_f = 1$ if a firm f in industry i reported important efforts to do product innovation. For changes in process we create a variable $\Delta Process_f = 1$ if the firm reported changes in process.
Product innovation does not necessarily mean an *increase* in product scope (suggested by our theory), since firms could simultaneously add and drop varieties or change the attributes of existent varieties. Therefore, in order to get closer to our theoretical mechanism, we use a further question from the survey related to product scope: 3. Importance of the innovation to increase product scope, $\Delta Scope_f$. This

[13]The PINTEC (2000) survey provides information for a total of 3,700 firms. However, for 630 of them information for many variables of interest is only available for the year 2000.

categorical variable (with four degrees of importance) relates innovation to changes in product scope.

For process innovation, the variable $\Delta Process_f$ may also not be directly related to the mechanism we propose in the theory (that some firms internalize spillover effects and, therefore, invest more in process innovation). Thus, to evaluate the importance of spillover effects, we use information related to changes in the flexibility of the production process. In particular, we use the following question from the survey:

4. Importance of the innovation to increase production flexibility, $\Delta Flexibility_f$.

$\Delta Flexibility_f$ is a categorical variable (with four degrees of importance) related to the ability of the firm to make the production process more flexible and increase the spillover effects among production lines. Therefore, it is consistent with the mechanism of the theoretical model, predicting that firms may internalize intra-firm spillover effects. The description of variables is found in Table 2.14 in the Appendix.

The data has the disadvantage of not capturing differences in the intensity of innovation across firms (variables are at most categorical, but not continuous). However, for the purposes of our study, we are able to capture the relevant mechanism, referring to the variation in innovation efforts *across industries*.

Table 2.1 presents summary statistics for the baseline indicators of innovation.[14] About half of the firms reported changes in process and 42 percent changes in product.[15] The interest of the study is to provide more information on the innovation choices of firms in different industries.

Table 2.1: Percentage of Firms by Innovation Status in the Year 2000

Product innovation	Process innovation	Product and process innovation
42%	48%	28%

[14] Values are based on a sample of 3,070 firms, for which we can exploit time-varying information (sample used in this chapter).

[15] 42 percent of firms conducted product innovation and 14 percent reported *only* product innovation (no process innovation). 48 percent of firms conducted process innovation and 20 percent *only* process innovation. 28 percent of the firms reported both product and process innovation.

2.3.2 Degree of Product Differentiation

For the analysis across firms, we create measures of the degree of product differentiation across sectors ($(1-e)_s$, for a sector s). For that, we match the firm-level innovation survey with information on the degree of product differentiation using (1) the Khandelwal (2010) classification of product differentiation and (2) the Rauch (1999) classification of goods, as follows.

Khandelwal (2010) Classification of Product Differentiation Khandelwal (2010) classifies sectors and products according to the degree of product differentiation and characterizes products as long and short "quality ladders". The paper uses nested logit estimations to infer product quality from price and quantity information of products exported to the United States: The quality of a product increases if its price can rise without losing market share. Quality ladders for each product are constructed from estimated qualities, calculated as the difference between the maximum quality (λ_p^{MAX}) and minimum quality (λ_p^{MIN}) within a product p, as follows: $\lambda_p = \lambda_p^{MAX} - \lambda_p^{MIN}$. In this specification, λ_p denotes the difference between the minimum and maximum of the estimated quality λ_{pct} of country c's exports to the United States at time t in product p. The higher λ_p, the higher the degree of product differentiation, such that the variation in market shares conditional on product prices is higher. Therefore, the mechanism proposed by Khandelwal (2010) is closely related to the mechanism we derive in the theory section (see Eqs. (2.6) and (2.7)). We use the Khandelwal (2010) product classification of the ladder length available at the 4-digit SIC1987 classification. This measure is mapped to the 2-digit IBGE classification of sectors and industries and generates a ladder length λ_s, as the average ladder over all products exported in sector s.

Rauch (1999) Classification of Goods Rauch (1999) classifies trade data into three groups of commodities: **w**, homogeneous (organized exchange) goods, which are goods traded in an organized exchange; **r**, reference priced goods, not traded in an organized exchange, but which have some quoted reference price, such as industry publications; and **n**, differentiated goods, without any quoted price. Using this classification at the 4-digit SITC product classification (issued by the United

Nations), we create a measure of the share of products from a firm classified as differentiated goods: $ShDiff_s = \frac{Nproducts_{s,n}}{Nproducts_{s,(w+r+n)}}$, where $ShDiff_s$ is the share of products produced by sector s classified as differentiated goods. Also in this case, we map the Rauch (1999) classification of goods to the 2-digit industry classification of differentiation from IBGE. Moreover, as an alternative measure, we estimate $ShSales_s = \frac{Sales_n}{TotalSales_{(w+r+n)}}$, where $ShSales_s$ is the share of sales of differentiated products in comparison to total sales in a sector s.[16]

We use λ_s as our benchmark measure, since λ_s provides higher variation in comparison to $ShDiff_s$. While λ_s is created from a continuous variable (*product ladder*), the Rauch (1999) classification is created from a binary variable (products classified as differentiated or non-differentiated goods). Thus, $ShDiff_s$ may be inaccurate and subject to measurement error. We keep the Rauch (1999) classification for robustness checks. Summary statistics for both measures of differentiation are shown in Table 2.2.

Table 2.2: Degree of Product Differentiation by Industry

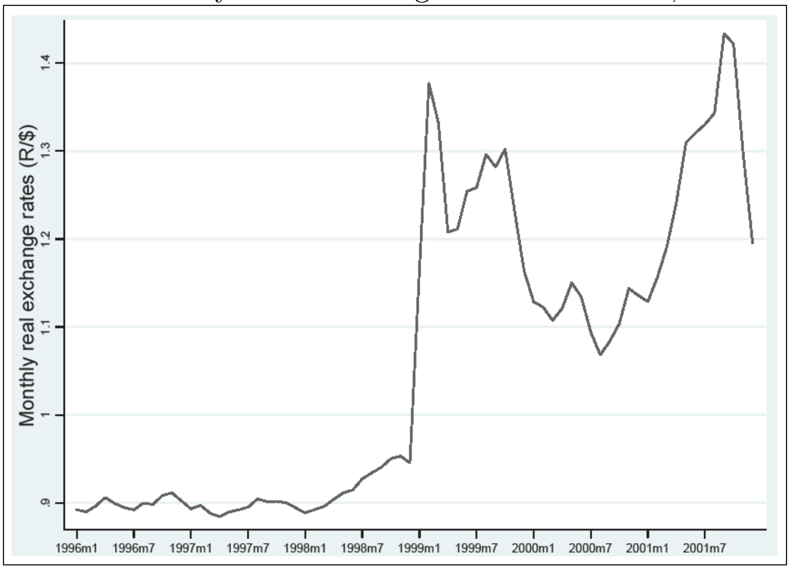
Measures of $(1-e)_s$	Observations	Mean	Std. Deviation	Min	Max
λ_s	3,070	1.73	0.21	1.10	2.27
$ShDiff_s$	3,070	0.73	0.12	0.33	1

2.3.3 Industry-specific Exchange Rates

In January 1999, the Brazilian government announced the end of the crawling peg, allowing the *real* to free float, with a consequent depreciation of the *real* by 25 percent (within a month). Figure 2.4 shows the evolution of the exchange rate in this period. While the size of the devaluation did not vary across different bilateral currencies, it varied across industries depending on the degree of openness to trade of the industry. We exploit the variation across time in exchange rates for industries with different degrees of exposure to global markets using trade-weighted industry-specific exchange rate shocks. In this way, we can empirically test the theoretical

[16] However, we believe that the share of differentiated products measured by the *number* of products ($ShDiff_s$) is a better measure to infer the degree of differentiation in comparison to the *sales* of products. Estimations using the share of sales ($ShSales_s$) remain significant (results available upon request).

Figure 2.4: Monthly Real Exchange Rates for Brazil, 1996-2001



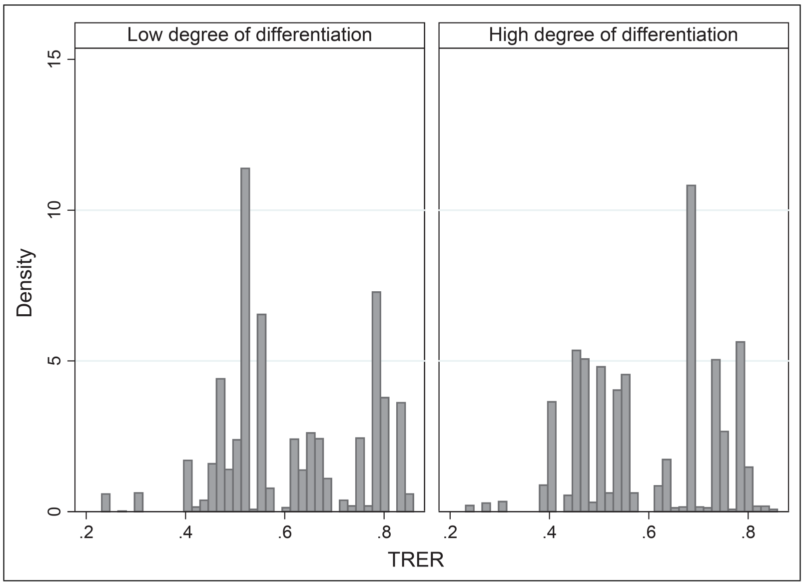
prediction that firms innovate more following an increase in market size (an increase in L in the model). Crucially, since all firms in our sample are permanent exporters, we expect them to react to the shock in a similar way.

Industry-specific exchange rates are constructed using yearly bilateral trade data from NBER-UN coded by Feenstra et al. (2005) and bilateral exchange rate data from the International Monetary Fund. The underlying idea of the industry-specific exchange rate shock is to study how the movements in different bilateral exchange rates with respect to the *real* affected different industries, depending on how much they trade with other countries. The bilateral trade data from NBER-UN provides information on bilateral trade flows at the 4-digit SITC level. The SITC classification is combined with the Brazilian CNAE industry classification using publicly available concordance tables up to 4-digit CNAE.[17] Following Goldberg (2004) and Almeida and Poole (2013), we calculate the industry-specific exchange rates as follows:

$$TRER_{it} = \sum_c \left(\left(0.5 \frac{X_{ict}}{\sum_c X_{ict}} + 0.5 \frac{M_{ict}}{\sum_c M_{ict}} \right) * rer_{ct} \right), \tag{2.36}$$

[17] Concordance tables are publicly available at: http://econweb.ucsd.edu/muendler/html/brazil.html#brazsec.

Figure 2.5: Industry Variation in Trade-weighted Real Exchange Rates for Firms in Industries with High and Low Degrees of Product Differentiation



where i is industry, c is country, and t is time, such that the bilateral real exchange rate rer_{ct}, measured by the Brazilian currency *real* with respect to the trading partner c, is weighted by the industry-specific trade shares. The industry-specific shares are time-varying import shares ($\frac{M_{ict}}{\sum_c M_{ict}}$) and export shares ($\frac{X_{ict}}{\sum_c X_{ict}}$) by industry and bilateral country pair.

Figure 2.5 shows the trade-weighted industry-specific exchange rates for firms above and below the mean of product differentiation (high or low mean λ_s). Two important facts must be mentioned. First, Figure 2.5 illustrates a substantial heterogeneity across industries in the trade-weighted exchange rates. Second, the figure shows that in both groups of firms/industries the distribution of $TRER_{it}$ is very similar, implying that there is no clear correlation between the degree of product differentiation and the openness of the industry.

Figure 2.6 in the Appendix reports changes in trade-weighted exchange rates over time. The right and left panels reveals that changes in $TRER_{it}$ are similar for both groups of industries (with high and low degree of differentiation, according to the Khandelwal (2010) classification).

2.3.4 Correlation between the Main Variables of Interest

The theoretical model predicts that firms in more differentiated industries will do more product and less process innovation in comparison to less differentiated industries. Table 2.3 shows the correlation between the innovation variables and our main variables for the degree of differentiation $(1-e)_s$: λ_s and $ShDiff_s$. We present the correlations in terms of product and process innovation ($\Delta Product_f$ and $\Delta Process_f$) as well as in terms of our alternative measure of innovation: While $\Delta Scope_f$ is related to product innovation (firms *introduce* new varieties and increase product scope), $\Delta Flexibility_f$ is related to the ability of the firm to increase the spillover effects among production lines.

Table 2.3: Correlation between $(1-e)_s$ and the Innovation Variables

$(1-e)_s$	$\Delta Product_f$	$\Delta Process_f$	$\Delta Scope_f$	$\Delta Flexibility_f$
λ_s	0.249***	-0.108**	0.054***	-0.085***
$ShDiff_s$	0.048***	-0.029**	0.016**	-0.031*

Note: *** indicates 1% significance, ** 5% significance, and * 10% significance.

We show that variables related to product innovation ($\Delta Product_f$ and $\Delta Scope_f$) are positively correlated with the degree of product differentiation. On the other hand, variables related to process innovation ($\Delta Process_f$ and $\Delta Flexibility_f$) are negatively correlated with the degree of product differentiation. Therefore, results in Table 2.3 are consistent with the predictions from the theoretical model. Moreover, in the section on robustness checks, we show that these correlations are not restricted to the data we use. We combine firm-level data from the World Bank with information on product and process innovation with industry-level data for Brazilian firms. The correlations between λ_s and innovation ($\Delta Product_f$ and $\Delta Process_f$) confirm our results.

2.4 Empirical Strategy

Our goal in the empirical part of this chapter is to test the predictions from the model regarding investment efforts of firms in industries with different scope for product differentiation, following a trade shock. To achieve identification, we estimate the incidence of changes in the innovation investments ΔI_f as a function of the degree of differentiation $(1-e)_s$ in the sector s in which the firm operates. To investigate the degree of differentiation $(1-e)_s$, we use two different measures: λ_s according to Khandelwal (2010) and $ShDiff_s$ following Rauch (1999), as described in the data section. We are interested in the differential effects for industries with different degrees of trade openness, measured by changes in time-varying trade-weighted shocks, $\Delta TRER_i$, as follows:

$$\Pr(\Delta I_f = 1) \; = \; F(\beta_1 \Delta TRER_i + \beta_2 \Delta TRER_i * (1-e)_s + \alpha_1 \Delta X_f + \upsilon_s + \varepsilon_f), \quad (2.37)$$

where f indexes the firm, i indexes the industry, s indexes the sector, and ΔX_f is a vector of firm-level time-varying control variables, as described in Table 2.14 in the Appendix. Initially, we include only changes in firm size, then subsequently we add further control variables. ε_f is a moving-average error term. υ_s are sector fixed effects, such that we can interpret results within industries in a given sector.[18] ΔI_f refers to innovation changes conducted by the firm, with $\Delta I_f = \Delta Process_f$ or $\Delta Product_f$. In alternative specifications, $\Delta I_f = \Delta Scope_f$ or $\Delta Flexibility_f$. For simplicity, we omit subscripts for Δ. Δ refers to the difference between years t (2000) and t_0 (1998), Δ_{t,t_0}.

In the theoretical model, we state that when market size grows (L increases), the increase in market size generates incentives for firms to innovate because of scale effects. Empirically, we test changes in market size using a major and unexpected exchange rate shock from 1999 as a source of variation (firms face varying degrees of exposure to foreign markets, and hence, in the access to foreign markets). We exploit this event using industry-specific exchange rate shocks computed over time, $\Delta TRER_i$. Following the predictions from the theoretical model, we expect $\beta_1 > 0$: An exchange rate devaluation increases incentives for firms to innovate (because of

[18] Note that in the theory we have used the words sector and industry interchangeably. In the empirics it is important that $TRER_i$ and $(1-e)_s$ have different levels of aggregation, such that the interaction term provides the relevant variation. Therefore, the fact that both variables come from different classification of goods/industries and are aggregated at different levels is an advantage in our approach. Moreover, there is no clear correlation between $(1-e)_s$ and between $TRER_i$ or $(1-e)_s$ and $\Delta TRER_i$, as we show in Figures 2.5 and 2.6. If the correlation was high, the interaction term could capture non linearities between innovation and the independent variables. Using the continuous measure of differentiation, λ_s , we find no statistically significant correlation between λ_s and $\Delta TRER_i$.

better access to foreign markets), in particular in industries more open to international trade.

On top of that, detailed information on the degree of differentiation ($(1-e)$ in the model) and on the type of innovation allows us to evaluate differential effects across industries and sectors. The differential effects are shown by β_2, our main coefficient of interest. β_2 captures the differential impact of the trade shock on firms in differentiated sectors relative to more homogeneous sectors. In response to the shock, scale effects create natural incentives for firms to expand innovation investments. In more differentiated sectors, cannibalization is lower such that firms invest more in product innovation, while in homogeneous sectors spillover effects from innovation are higher such that firms invest more in process innovation. Therefore, $\beta_2 > 0$ in case the dependent variable is $\Delta Product_f$, i.e. firms in sectors with a high degree of product differentiation invest more in product innovation, and $\beta_2 < 0$ when the dependent variable is $\Delta Process_f$ (firms in more differentiated sectors invest less in process innovation in comparison to firms in more homogeneous sectors).

Our main empirical equation is tested in a first-differences model. Concerning the functional form, we estimate our empirical model using probit and linear probability models, which have different advantages and disadvantages. The linear probability model has the advantage of being easy to estimate and to interpret the coefficients. However, though unbiased, it poses important disadvantages. For instance, the assumption that the error term has unlimited range is not correct, causing problems for hypothesis testing. Moreover, the fitted probabilities may be outside the zero-one boundaries and the marginal impact of β_2 does not exhibit diminishing returns, which would be otherwise expected from the nature of probabilities (the marginal impact should decrease as the independent variable increases). To deal with the concerns with the linear estimation, we estimate the random effects probit model, where $F(.)$ is the normal cumulative distribution function. Finally, we also conduct robustness checks using seemingly unrelated regressions - SUR, to allow the error terms across equations to be correlated (equations with $\Delta Process_f$ or $\Delta Product_f$ as dependent variable).

2.5 Results

Tables 2.4 and 2.5 present the main empirical results from our analysis. In Table 2.4, we first investigate whether changes in market size lead to more innovation. As predicted by the theoretical model, when the market size grows (L increases) incentives to innovate increase for all firms and all types of innovation ($\beta_1 > 0$). Columns (1) to (4) in Table 2.4 confirm that $\beta_1 > 0$ for product and process innovation, meaning an increase in the predicted probability of innovation: Following an industry-specific exchange rate devaluation ($\Delta TRER_i > 0$), firms have higher incentives to invest in product and process innovation. Results are statistically significant using LPM and Probit, shown in the odds and even columns, respectively. Unless otherwise stated, results reported for Probit in the tables include the coefficients, their standard errors, and the value of the likelihood function. To better quantify the results in Table 2.4, we estimate the marginal effect computed at means of all variables (means are reported in Tables 2.2 and 2.13), keeping in mind that probit implies diminishing marginal magnitudes depending on the values of dependent variables. At mean values, the average marginal effect is around 0.27 for product and 0.31 for process innovation, with a p-value of 0.001 in both cases, meaning that the effect is significant.

Table 2.4: Effect of $\Delta TRER_i$ on Innovation

Dependent variable:	$\Delta Process_f$		$\Delta Product_f$	
	Probit	LPM	Probit	LPM
	(1)	(2)	(3)	(4)
$\Delta TRER_i$	0.768***	0.296***	0.703***	0.259***
	(0.221)	(0.0819)	(0.218)	(0.0778)
Constant	yes	yes	yes	yes
$\Delta logNworkers_f$	yes	yes	yes	yes
Sector s fixed effects	yes	yes	yes	yes
Log-pseudolikelihood	-1895.239		-1776.380	
Pseudo R-squared	0.010		0.039	
R-squared		0.104		0.146
Observations	3,070	3,070	3,070	3,070

However, the main interest of our analysis refers to the differential effects across sectors and industries. The differential effects using our main measure of differentiation

λ_s are shown in Table 2.5. Results confirm the main predictions from our theoretical model. Following an exchange rate devaluation ($\Delta TRER_i > 0$), firms in industries with a high degree of product differentiation invest more in product innovation relative to other firms ($\beta_2 > 0$ when $\Delta I_f = \Delta Product_f$), while firms in industries with a low degree of product differentiation invest more in process innovation relative to other firms ($\beta_2 < 0$ when $\Delta I_f = \Delta Process_f$). Results hold for both estimation strategies (Probit and LPM).

Table 2.5: Effect of $\Delta TRER_i$ on Innovation for Firms in Different Industries

Dependent variable:	$\Delta Process_f$		$\Delta Product_f$	
	Probit	LPM	Probit	LPM
	(1)	(2)	(3)	(4)
$\lambda_s * \Delta TRER_i$	-0.316***	-0.124***	0.278***	0.106***
	(0.0840)	(0.0331)	(0.0412)	(0.0154)
$\Delta TRER_i$	0.868***	0.329***	0.553**	0.199**
	(0.224)	(0.0810)	(0.218)	(0.0773)
Constant	yes	yes	yes	yes
$\Delta logNworkers_f$	yes	yes	yes	yes
Sector s fixed effects	yes	yes	yes	yes
Log-pseudolikelihood	-1892.544		-1775.112	
Pseudo R-squared	0.011		0.040	
R-squared		0.104		0.147
Observations	3,070	3,070	3,070	3,070

For probit, results in Table 2.5 columns (1) and (3) report the coefficients. To evaluate magnitudes, we compute the difference in probabilities depending on different values of $\Delta TRER_i$ and λ_s, since the value of the interaction effect changes upon the value of the continuous predictor variable. At mean values of all variables, the marginal effect of $\Delta TRER_i$ is 0.21 for product and 0.34 for process innovation. For the interaction term, the marginal effect is 0.10 for product and -0.12 for process innovation, evaluated at mean values. Marginal effects are in all cases statistically significant at the one percent level. Therefore, we confirm that firms in more homogeneous sectors are significantly more likely to do process innovation following the shock, whereas firms in more differentiated sectors are more likely to do product innovation. Columns (2) and (4) report results for the LPM. If we evaluate mean values of $\Delta TRER_i$ and λ_s, a decrease in λ_s by two standard deviations leads to an increase in the probability to do process innovation by roughly two percent, with this value being higher for firms in sectors with higher initial λ_s. For product innovation, an increase in λ_s by two standard deviations leads to an increase in product innovation by roughly four percent.

One may argue that the measures of product and process innovation used in Table 2.5 are disconnected from the theoretical model. Changes in process innovation ($\Delta Process_f$) may reflect an innovation not directly related to internalization of spillovers. We address this concern using an alternative measure of innovation related to spillover effects, $\Delta Flexibility_f$. Results presented in Table 2.6 reveal that estimations are robust to this alternative measure of process innovation.

A similar concern refers to the mechanism related to product innovation ($\Delta Product_f$). Investments in product innovation may reflect changes in an already existent product rather than the creation of an additional variety. We address this concern using an alternative measure of innovation related to changes in product scope, $\Delta Scope_f$. Results shown in Table 2.6 are consistent with the baseline estimations from Table 2.5.

Table 2.6: Effect of $\Delta TRER_i$ on Product Scope and Production Flexibility

Dependent variable:	$\Delta Scope_f$		$\Delta Flexibility_f$	
	Probit	LPM	Probit	LPM
	(1)	(2)	(3)	(4)
$\lambda_s * \Delta TRER_i$	0.195***	0.0497***	-0.164***	-0.0614***
	(0.0620)	(0.0123)	(0.0527)	(0.0196)
$\Delta TRER_i$	0.594***	0.303***	0.745**	0.272**
	(0.194)	(0.0548)	(0.314)	(0.114)
Constant	yes	yes	yes	yes
$\Delta logNworkers_f$	yes	yes	yes	yes
Sector s fixed effects	yes	yes	yes	yes
Log-pseudolikelihood	-567.767		-1255.563	
Pseudo R-squared	0.050		0.019	
R-squared		0.094		0.069
Observations	3,070	3,070	1,971	1,971

2.6 Robustness Checks

Rauch (1999) Measure of Product Differentiation We use $ShDiff_s$ as an alternative measure to λ_s and replicate the interaction effects from Table 2.5. Results are shown in Table 2.7 columns (1) and (3). While smaller in magnitudes, the effect confirms the expected coefficients for β_1 and β_2.

Degree of Differentiation: Firm-level Measure As a further alternative measure to λ_s, we build a firm-level ladder λ_f starting from the 10-digit product classification, made available by Khandelwal (2010). This measure allows us to exploit the degree of differentiation at the firm-level, since we have information on all 6-digit products exported by Brazilian firms. Thus, we combine these data and create the mean ladder at the firm level λ_f corresponding to the average *ladder* of the products exported by the firm, as follows: $\lambda_f = \frac{\sum_{fp} \lambda_{fp}}{N}$, where N is the initial number of products exported by the firm in the year 1998. λ_f provides higher variation in comparison to λ_s: While λ_s has a standard deviation of 0.21, λ_f has a standard deviation of 0.6. The means are very close, 1.73 for λ_s and 1.75 for λ_f.
Results using λ_f are shown in Table 2.7 in columns (2) and (4) and are consistent with our predictions. However, data at the firm and product-level on the degree of differentiation are not essential to our argument and may be subject to endogeneity once we exploit time variation.[19] Therefore, our preferred empirical specification uses information at the sector and industry-level.

Asymmetries across Firms One important concern with our baseline estimations refers to firms that do both types of innovation. Many firms invest simultaneously in product and process innovation following the exchange rate shock. Therefore, we evaluate asymmetries across different groups of firms. In particular, we evaluate the effects for firms that do only one type of innovation.
While the baseline estimations using $\Delta I_f = \Delta Process_f$ or $\Delta Product_f$ consider all firms that reported process and product innovation efforts, respectively, here we

[19]For instance, if firms invest in product innovation they may increase the degree of differentiation of the products they offer over time. However, at the industry level this effect is less severe and does not affect our main predictions.

evaluate the effect for firms that reported only one *or* the other type of innovation. $\Delta Process\_only_f = 1$ for firms that reported only process innovation, zero otherwise. Similar for product innovation ($\Delta Product\_only_f$). Estimations with $\Delta Process\_only_f$ and $\Delta Product\_only_f$ as dependent variables reveal that results are in general larger in magnitudes for firms reporting only one type of innovation (results in columns (1) to (4) from Table 2.8). We interpret this result as follows: Firms in the extremes of the distribution of product differentiation have lower incentives to invest in both types of innovation. Imagine firms producing bricks versus firms producing luxury watches (a highly homogeneous and a highly differentiated product, respectively). While firms in the middle of the distribution will have higher incentives to allocate part of their resources to each type of innovation, firms in the extremes of the distribution such as watches and bricks have higher returns to innovation when they allocate resources in only one type of innovation.

Results Adding further Firm-level Control Variables We add several firm-level variables to the main specification and show that results remain stable. The stability of results suggest that omitted variables might not be a major concern.
The variables we add relate to firm initial characteristics in year 1998, $X_{f,t=0}$. Firms that are larger, foreign-owned, and with a more skilled labor force are in general more innovative. Therefore, we investigate the stability of our results when adding the following firm initial conditions: Number of workers as a proxy for firm size ($\log Nworkers_{f,t=0}$), foreign ownership dummy ($FDI_{f,t=0}$), share of workers with tertiary education as a proxy for worker skills ($Skills_{f,t=0}$), the number of products exported by the firm ($\log Nproducts_{f,t=0}$), and the number of destinations of exports ($\log Ndestinations_{f,t=0}$). The description of variables and the associated means and standard deviations are reported in Table 2.13.
Results are shown in Table 2.9. As expected, all coefficients are positive and statistically significant, meaning that larger, foreign-owned, and firms with a higher share of skilled workers do more innovation. Crucially, as shown in Table 2.9, the interaction term shown by β_2 remains significant and stable through all specifications. In results available upon request, we also add the change in these same variables over the period. While the point estimates are in many cases not statistically significant (since the period is relatively short), the signs are informative and consistent with

the literature.

Results Using SUR We check whether our results remain robust to further estimations strategies. In the baseline results, we have estimated LPM and Probit separately for product and process innovation. To allow the error terms of the two equations to be correlated, we estimate a seemingly unrelated regressions model (SUR). Results reported in Table 2.11 reveal that coefficients are the same in comparison to the LPM (as expected), but the error terms are slightly higher when we allow them to be correlated. Results remain significant in all cases.

Exchange Rate Shock: Alternative Measures We conduct several robustness checks to evaluate the stability of our results with respect to alternative measures of $\Delta TRER_i$.

First, we look at lagged exports. One concern with the estimations using $\Delta TRER_i$ is endogeneity between trade and the exchange rate. We avoid this concern using lagged import shares ($\frac{M_{ic,t-1}}{\sum_c M_{ic,t-1}}$) and lagged export shares ($\frac{X_{ic,t-1}}{\sum_c X_{ic,t-1}}$). Columns (1) and (2) in Table 2.10 show that results remain robust when we use lagged exports. *Second*, instead of using industry-specific import shares ($\frac{M_{ict}}{\sum_c M_{ict}}$) and export shares ($\frac{X_{ict}}{\sum_c X_{ict}}$) to construct $TRER_{it}$, we construct an alternative measure using only export shares, as follows: $XTRER_{it} = \sum_c \left(\frac{X_{ict}}{\sum_c X_{ict}} * rer_{ct} \right)$. The advantage of using export shares separately is to separate export shocks from import shocks. One concern with the estimations using $\Delta TRER_i$ is that an exchange rate shock may mean increases in market size for some industries but not for others (depending on input intensity, among others). Using the exchange rate shock separately for imports and exports, we exploit whether factors unrelated to market size are driving our results. Results are reported in Table 2.10 in columns (3) and (4). Also in this case our main hypotheses remain robust.

Results Using Innovation Data from the World Bank One could argue that the correlation we find between λ_s and product/process innovation is specific to our data. To overcome this concern, we use firm-level innovation data from the World Bank (Business Environment and Enterprise Performance Survey (BEEPS)) for Brazil in the year 2003. The innovation survey contains information on investments in product and process innovation. We build the following variables for product and process innovation. $Product\_WB_f = 1$ if the firm answered *yes* to the following question: "Initiative undertaken in last 3 years: new product line?", otherwise $Product\_WB_f = 0$. $Process\_WB_f = 1$ if the firm answered *yes* to the following question: "Initiative undertaken in last 3 years: new technology?", otherwise $Process\_WB_f = 0$. We combine the World Bank data with the Khandelwal (2010) measure of differentiation using the Brazilian industry classification available at the World Bank.

The World Bank data do not allow us to fully test our model. However, we can calculate the correlation between λ_s and innovation ($Product\_WB_f$ and $Process\_WB_f$) and compare with the correlations we find using the PINTEC (2000) data. Results shown in Table 2.12 confirm the correlations presented in Table 2.3 using the PINTEC (2000) firm-level data.

2.7 Conclusion

This chapter is inspired by growing evidence on the importance of within-firm adjustments in explaining gains from trade. A recent strand of the literature in international trade emphasizes that innovating firms account for a large fraction of the productivity and variety gains within sectors. In this chapter, we provide a new model of MPFs, allowing for endogenous investments in both product and process innovation. Following an increase in the market size, we show how firms increase investments of both types. The focus of this model, however, is on an industry-specific trade-off between the two types of innovation, which arises through demand and cost linkages specific to MPFs. Both linkages are related to the degree of product differentiation in a sector, leading to heterogenous returns to the two types of innovation across industries.

Our model shows that firms in sectors with a high scope for differentiation invest more in product and less in process innovation. In a highly differentiated industry, returns to product innovation are high as cannibalization effects within the firm are low. Returns to process innovation, however, are lower in a differentiated sector as more differentiated products are associated with more dissimilar production processes. Therefore, in more differentiated sectors, process innovation is highly product-specific and is not applicable to the whole range of products within the firm. Obviously, for firms in homogeneous industries, the mechanism works exactly the other way round.

Our model provides novel predictions, which are tested using Brazilian firm-level data. We combine detailed information on the two types of innovation featured in our theory with an unexpected exchange rate devaluation as an exogenous source of variation to test the effect of market size on innovation. For Brazilian exporters, the currency devaluation improves foreign market access without losing domestic market shares. We find that, given the larger market, firms reoptimize their investments and increase spending in both types of innovation. Moreover, we are able to evaluate differential effects across industries. Using several measures for the degree of product differentiation in a sector, we show that firms in differentiated sectors focus on product innovation while firms in more homogeneous sectors innovate more in better processes.

2.8 Appendix

2.8.1 Derivation of Eq. (2.31)

Combining Eqs. (2.19) at $i = \delta$ and (2.24) yields:

$$b'r_k\left(1-e\right)x\left(\delta\right)^2 = \left(\left(1-\theta\left(e\right)\right)x\left(\delta\right)+\theta\left(e\right)X\right)\left(\left(1-\theta\left(e\right)\right)x\left(\delta\right)-\theta\left(e\right)X\right)+r_\delta r_k. \tag{2.38}$$

The first expression on the right-hand side can be rewritten as: $\left(\left(1-\theta\left(e\right)\right)x\left(\delta\right)\right)^2 - \left(\theta\left(e\right)X\right)^2$. Solving for $x\left(\delta\right)$ yields the expression in Eq. (2.31).

2.8.2 Market Size Effect - Proposition 2.1

We totally differentiate the two equilibrium conditions for scale and scope in Eqs. (2.28) and (2.32) and write the results in matrix notation.

$$\left[\begin{array}{cc} r_k\delta\left(a-c-c_1\frac{\delta}{2}\right) & -2\left(b'r_k(1-e)-(1-e^\kappa)^2\right)x\left(\delta\right)\delta \\ \left(\left(eb'r_k-e^\kappa\left(2\left(1-e^\kappa\right)+e^\kappa\delta\right)\right)-\frac{e^{2\kappa}X}{x(\delta)}\right)2X & \left(r_kc_1-2e^{2\kappa}X\right)\delta \end{array}\right]*$$

$$\left[\begin{array}{c} d\ln X \\ d\ln\delta \end{array}\right] = -\left[\begin{array}{c} 2X(1-e+e\delta) \\ \left(\left(1-e\right)x\left(\delta\right)+2eX\right) \end{array}\right]b'r_kd\ln b' + \left[\begin{array}{c} \delta \\ 1 \end{array}\right]r_kad\ln a \tag{2.39}$$

To derive this matrix, we use information from Eqs. (2.28), (2.30), and (2.31). The determinant Δ of the system is always positive. The fact that $\Delta > 0$ ensures a unique and stable equilibrium. Condition 2.1 stated in Eq. (2.23) ensures that $\left(\left(eb'r_k-e^\kappa\left(2\left(1-e^\kappa\right)+e^\kappa\delta\right)\right)-\frac{e^{2\kappa}X}{x(\delta)}\right) > 0$. To proof the latter result, we compute an alternative expression for total firm scale by integrating over per variety scale in Eq. (2.25):

$$X = \frac{c_1\left(\frac{\delta^2}{2}\right)}{2\left(b'(1-e)-\frac{(1-e^\kappa)^2}{r_k}\right)} + \delta x\left(\delta\right). \tag{2.40}$$

Combining the latter expression with the condition in Eq. (2.23) yields:

$$eb'r_k x(\delta) > 2e^{\kappa}(1-e^{\kappa})x(\delta) + e^{2\kappa}\delta x(\delta) + e^{2\kappa}X + e^{2\kappa}\frac{c_1\left(\frac{\delta^2}{2}\right)}{2\left(b'(1-e) - \frac{(1-e^{\kappa})^2}{r_k}\right)}, \quad (2.41)$$

and ensures that $\Delta > 0$.

Effect on Firm Scale X: The effect of an increase (decrease) in L (b') on total firm size can be expressed as follows:

$$\frac{d\ln X}{d\ln b'} = \frac{1}{\Delta}\begin{vmatrix} -2X(1-e+e\delta)b'r_k & -2\left(b'r_k(1-e) - (1-e^{\kappa})^2\right)x(\delta)\delta \\ -\left((1-e)x(\delta) + 2eX\right)b'r_k & \left(r_k c_1 - 2e^{2\kappa}X\right)\delta \end{vmatrix} < 0. \quad (2.42)$$

As the sign of the matrix is clearly negative, an increase in the market size increases total firm size X. An increase in the demand intercept a, leads to the same qualitative result:

$$\frac{d\ln X}{d\ln a} = \frac{1}{\Delta}\begin{vmatrix} \delta a r_k & -2\left(b'r_k(1-e) - (1-e^{\kappa})^2\right)x(\delta)\delta \\ a r_k & \left(r_k c_1 - 2e^{2\kappa}X\right)\delta \end{vmatrix} > 0. \quad (2.43)$$

Effect on Optimal Scope δ: The effect of an increase (decrease) in L (b') on optimal scope can be expressed as follows:

$$\frac{d\ln \delta}{d\ln b'} = \frac{1}{\Delta}\begin{vmatrix} r_k\delta\left(a - c - c_1\frac{\delta}{2}\right) & -2X(1-e+e\delta)b'r_k \\ \left(\left(eb'r_k - e^{\kappa}\left(2(1-e^{\kappa}) + e^{\kappa}\delta\right)\right) - \frac{e^{2\kappa}X}{x(\delta)}\right)2X & -\left((1-e)x(\delta) + 2eX\right)b'r_k \end{vmatrix} < 0. \quad (2.44)$$

Note that the sign of the matrix $\Delta_{b'}$ can be defined unambiguously as:

$$\Delta_{b'} = -\left\{\begin{array}{c} \left(b'r_k(1-e+e\delta) - (1-e^{\kappa}+e^{\kappa}\delta)^2\right)\left((1-e)x(\delta)\right) \\ +2X\left(\left(2e^{\kappa}(1-e^{\kappa}) - e(1-e^{2\kappa}) + (1-e)e^{2\kappa}\delta\right) + (1-e+e\delta)\frac{e^{2\kappa}X}{x(\delta)}\right) \end{array}\right\} < 0. \quad (2.45)$$

Therefore, an increase in the market size clearly induces the firm to increase its optimal product range. Again, we derive the same qualitative result for an increase in a:

$$\frac{d\ln\delta}{d\ln a}=\frac{1}{\Delta}\begin{vmatrix} r_k\delta\left(a-c-c_1\frac{\delta}{2}\right) & \delta a r_k \\ \left(\left(eb'r_k-e^{\kappa}\left(2\left(1-e^{\kappa}\right)+e^{\kappa}\delta\right)\right)-\frac{e^{2\kappa}X}{x(\delta)}\right)2X & ar_k \end{vmatrix}>0. \tag{2.46}$$

The sign of the matrix Δ_a is clearly positive as:

$$\Delta_a=\left(b'r_k(1-e)-1+e^{\kappa}\left(2-e^{\kappa}\right)+\frac{e^{2\kappa}\delta X}{x\left(\delta\right)}\right)2Xar_k>0. \tag{2.47}$$

Effect on Process Innovation K: After having determined the market size effects on scale X and scope δ, identifying the market size effect on process innovation K is trivial. Totally differentiating Eq. (2.29) yields the following results:

$$r_kK\frac{d\ln K}{d\ln b'}=\left(1-e^{\kappa}+e^{\kappa}\delta\right)X\underbrace{\frac{d\ln X}{d\ln b'}}_{<0}+e^{\kappa}\delta X\underbrace{\frac{d\ln\delta}{d\ln b'}}_{<0}<0, \tag{2.48}$$

and

$$r_kK\frac{d\ln K}{d\ln a}=\left(1-e^{\kappa}+e^{\kappa}\delta\right)X\underbrace{\frac{d\ln X}{d\ln a}}_{>0}+e^{\kappa}\delta X\underbrace{\frac{d\ln\delta}{d\ln a}}_{>0}>0. \tag{2.49}$$

The result clearly shows that an increase in the market size L or the demand intercept a will induce the firm to invest more in better processes.

2.8.3 Effect of the Degree of Product Differentiation - Proposition 2.2

Differentiating Eq. (2.32) with respect to e and substituting information from Eq. (2.31), gives:

$$\frac{\partial\ln\delta}{\partial\ln e}=-\frac{\left(\left(2X-x\left(\delta\right)\right)\left(eb'r_k-2\kappa e^{\kappa}\left(1-e^{\kappa}\right)\right)x\left(\delta\right)-2\kappa e^{2\kappa}X\left(2\left(\delta-1\right)x\left(\delta\right)+X\right)\right)}{\left(c_1r_k-2e^{2\kappa}X\right)x\left(\delta\right)\delta}. \tag{2.50}$$

For very strong (weak) spillovers, i.e. low (high) values of κ holds: $\lim_{\kappa\to 0}\frac{\partial\ln\delta}{\partial\ln e}<0$ and $\lim_{\kappa\to\infty}\frac{\partial\ln\delta}{\partial\ln e}<0$. For intermediate values of spillovers, the sign of the derivative in Eq. (2.50) depends on the perceived costs of process innovation $b'r_k$ (see discussion of Condition 2.1). If costs for process innovation are sufficiently high, then: $\frac{\partial \ln \delta}{\partial \ln e} < 0$. Furthermore, we can take the derivative of Eq. (2.32) with respect to e and evaluate it at $e = 0$:

$$\frac{\partial \delta}{\partial e} \mid_{e=0} = -\frac{b' \left(2X - x\left(\delta\right)\right)}{c_1} < 0. \tag{2.51}$$

The latter implies that even in the case of perfectly differentiated products, a small increase in e will reduce the optimal product range δ.

2.8.4 Robustness Checks

Table 2.7: Effect of $\Delta TRER_i$ on Innovation Using Alternative Measures of Differentiation

Dependent variable:	$\Delta Process_f$		$\Delta Product_f$	
	$ShDiff_s$	λ_f	$ShDiff_s$	λ_f
	LPM	LPM	LPM	LPM
	(1)	(2)	(3)	(4)
$ShDiff_s * \Delta TRER_i$	-0.0649***		0.0857***	
	(0.0180)		(0.0177)	
$\lambda_f * \Delta TRER_i$		-0.140***		0.129***
		(0.0459)		(0.0127)
$\Delta TRER_i$	0.301***	0.414***	0.252***	0.259***
	(0.0808)	(0.158)	(0.0768)	(0.0778)
Constant	yes	yes	yes	yes
$\Delta logNworkers_f$	yes	yes	yes	yes
Sector s fixed effects	yes	yes	yes	yes
R-squared	0.104	0.104	0.146	0.147
Observations	3,070	3,070	3,070	3,070

Table 2.8: Effect of $\Delta TRER_i$ for Firms that Do only One Type of Innovation

Dependent variable:	Only process innovation		Only product innovation	
	Probit	LPM	Probit	LPM
	(1)	(2)	(3)	(4)
$\lambda_s * \Delta TRER_i$	-0.657***	-0.179***	0.509***	0.102***
	(0.154)	(0.0421)	(0.123)	(0.0245)
$\Delta TRER_i$	1.895***	0.512***	0.942***	0.201***
	(0.543)	(0.153)	(0.279)	(0.0720)
Constant	yes	yes	yes	yes
$\Delta logNworkers_f$	yes	yes	yes	yes
Sector s fixed effects	yes	yes	yes	yes
Log-pseudolikelihood	-1343.687		-1051.554	
Pseudo R-squared	0.084		0.086	
R-squared		0.109		0.121
Observations	3,070	3,070	3,070	3,070

Table 2.9: Effect of $\Delta TRER_i$ on Innovation - Results Adding further Control Variables

Dependent variable:	$\Delta Process_f$					$\Delta Product_f$				
	LPM									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$\Delta TRER_i$	0.356***	0.366***	0.315***	0.334***	0.358***	0.220***	0.238***	0.169**	0.195***	0.212***
	(0.0783)	(0.0795)	(0.0775)	(0.0801)	(0.0803)	(0.0764)	(0.0715)	(0.0742)	(0.0739)	(0.0785)
$\lambda_s * \Delta TRER_i$	-0.120***	-0.181***	-0.146***	-0.159***	-0.121***	0.106***	0.0918***	0.108***	0.0981***	0.109***
	(0.0321)	(0.0344)	(0.0322)	(0.0335)	(0.0320)	(0.0153)	(0.0149)	(0.0149)	(0.0151)	(0.0153)
$\log Ndestinations_{f,t=0}$	0.0970***					0.0808***				
	(0.00795)					(0.00795)				
$Skills_{f,t=0}$		0.391***					0.890***			
		(0.0718)					(0.0695)			
$\log Nproducts_{f,t=0}$			0.0880***					0.118***		
			(0.00728)					(0.00680)		
$FDI_{f,t=0}$				0.161***					0.257***	
				(0.0241)					(0.0234)	
$\log Nworkers_{f,t=0}$					0.0859***					0.0785***
					(0.00703)					(0.00677)
Constant	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
$\Delta \log Nworkers_f$	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Sector s fixed effects	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
R-squared	0.142	0.107	0.132	0.112	0.166	0.177	0.168	0.195	0.163	0.191
Observations	3,070	3,070	3,070	3,070	3,070	3,070	3,070	3,070	3,070	3,070

Table 2.10: Effect on Innovation Using Alternative Measures of $TRER_{it}$

	LPM			
Dependent variable:	$\Delta Process_f$	$\Delta Product_f$	$\Delta Process_f$	$\Delta Product_f$
	(1)	(2)	(3)	(4)
$\lambda_s * \Delta TRER_{i,t-1}$	-0.118***	0.0903***		
	(0.0438)	(0.0147)		
$\Delta TRER_{i,t-1}$	0.295***	0.194**		
	(0.0829)	(0.0901)		
$\lambda_s * \Delta XTRER_i$			-0.276***	0.163***
			(0.0425)	(0.0386)
$\Delta XTRER_i$			0.359***	0.414***
			(0.0794)	(0.158)
Constant	yes	yes	yes	yes
$\Delta \log Nworkers_f$	yes	yes	yes	yes
Sector s fixed effects	yes	yes	yes	yes
R-squared	0.105	0.147	0.104	0.149
Observations	3,041	3,041	3,070	3,070

Table 2.11: Effect of $\Delta TRER_i$ on Innovation Using SUR

	SUR 1		SUR 2	
Dependent variable:	$\Delta Process_f$	$\Delta Product_f$	$\Delta Process_f$	$\Delta Product_f$
	(1)	(2)	(3)	(4)
$\lambda_s * \Delta TRER_i$			-0.124***	0.106***
			(0.0334)	(0.0155)
$\Delta TRER_i$	0.296***	0.259***	0.329***	0.199**
	(0.0907)	(0.0896)	(0.0920)	(0.0899)
Constant	yes	yes	yes	yes
$\Delta logNworkers_f$	yes	yes	yes	yes
Sector s fixed effects	yes	yes	yes	yes
R-squared	0.104	0.146	0.107	0.149
Observations	3,070	3,070	3,070	3,070

Table 2.12: Correlation between $(1-e)_s$ and Innovation Using World Bank Data

$(1-e)_s$	$Process\_WB_f$	$Product\_WB_f$
λ_s	-0.0893	0.0105

Notes: For the estimations we have used 1397 firms for which we could combine firm-level data with the Khandelwal (2010) classification of goods. The World Bank Survey for Brazil was conducted in year 2003.

2.8.5 Data Appendix

Table 2.13: Summary Statistics of Main Variables

Variable	Obs	Mean	Std. Dev.
$FDI_{f,t=0}$	3,070	0.184	0.388
$Skills_{f,t=0}$	3,070	0.120	0.130
$\log Ndestinations_{f,t=0}$	3,070	1.543	1.036
$\log Nproducts_{f,t=0}$	3,070	1.476	1.167
$\log Nworkers_{f,t=0}$	3,070	5.503	1.180
$\Delta \log Nworkers_f$	3,070	0.039	0.463
λ_s	3,070	1.73	0.21
λ_f	3,070	1.74	0.60
$ShDiff_s$	3,070	0.73	0.12
$\Delta TRER_i$	3,070	0.256	0.076
$TRER_{it}$	6,140	0.608	0.138

Figure 2.6: $\Delta TRER_i$ for Industries with Different Degrees of Product Differentiation

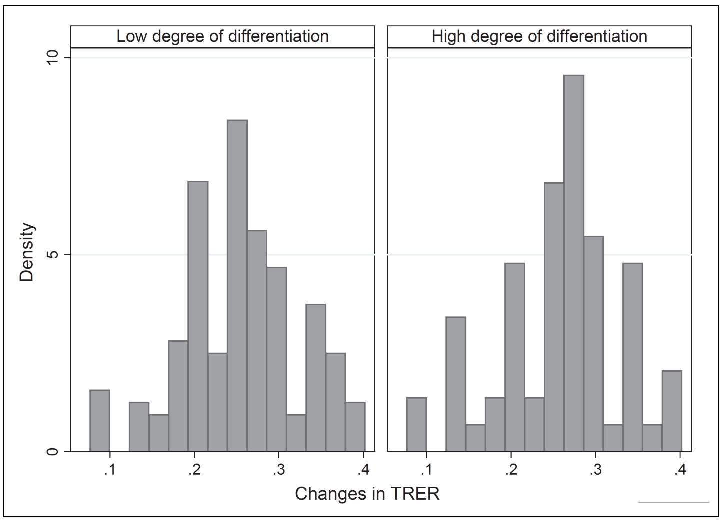


Table 2.14: Description of the Dependent Variable and Main Explanatory Variables

Variable	Variable description	Data source
Innovation variables:		
$\Delta Process_f$	$\Delta Process_f = 1$ if	PINTEC (2000)
	the firm reported changes in the production process in the period 1998-2000	
	(questions v10 and v11 from the survey)	
$\Delta Product_f$	$\Delta Product_f = 1$ if	PINTEC (2000)
	the firm reported product innovation in the period 1998-2000	
	(questions v07 and v08 from the survey)	
$\Delta Scope_f$	$\Delta Scope_f = 1$ if	PINTEC (2000)
	Innovation was important to increase product scope (question v78)[1]	
$\Delta Flexibility_f$	$\Delta Flexibility_f = 1$ if	PINTEC (2000)
	Innovation was important to increase product flexibility(question v83)[1]	
Exchange rates:		
$TRER_{it}$	Industry-specific exchange rates	NBER-UN
	$\sum_c \left(\left(0.5\frac{X_t^{sc}}{\sum_c X_t^{sc}} + 0.5\frac{M_t^{sc}}{\sum_c M_t^{sc}}\right) rer_t^c\right)$	and IMF
Degree of product differentiation:		
λ_s	Degree of product differentiation based on Khandelwal (2010)	Khandelwal (2010)
	λ_s is the average by sector s , defined according to the IBGE classification.	
λ_f	Degree of product differentiation based on Khandelwal (2010)	Khandelwal (2010)
	$\lambda_f = \frac{\sum_{fp} \lambda_{fp}}{N}$, where p is a HS 6-digit product exported by the firm.	
$ShDiff_s$	Share of differentiated products in s, following Rauch (1999)	Rauch (1999)
Firm initial characteristics:		
$FDI_{f,t=0}$	Foreign ownership dummy	PINTEC(2000)
$Nworkers_{f,t=0}$	Number of workers in f (measure of firm size).	RAIS-Brazil
$Skills_{f,t=0}$	Share of workers with tertiary education as a proxy for workers skills	RAIS-Brazil
$Ndestinations_{f,t=0}$	Number of export destinations	SECEX
$Nproducts_{f,t=0}$	Number of products exported	SECEX

Notes: The innovation survey is available at:

`http://www.pintec.ibge.gov.br/downloads/PUBLICACAO/Publicacao%20PINTEC%202000.pdf`

1. Questions answered according to their relative importance: (i) high, (ii) medium, (iii) low or (iv) does not apply.

We assume that the variable is equal one (i.e., important) if the firm answered either (i) or (ii).

Chapter 3

Multi-Product Firms, Endogenous Sunk Costs, and Gains from Trade through Intra-Firm Adjustments

3.1 Introduction

In 1942, Joseph Schumpeter argued that innovation activity is carried out by large firms, for whom R&D is endogenous. R&D projects often go hand in hand with high development costs and, therefore, a sufficiently large scale of firm sales is required to cover these costs. Trade liberalization increases the effective size of the market, which induces innovation activities through economies of scale. These findings are validated by recent empirical studies. For Canadian and Argentinian firms, Lileeva and Trefler (2010) and Bustos (2011) document that reductions in tariffs lead to investments in productivity-enhancing activities by exporting firms. After trade liberalization, exporters who benefit from the larger market are more technology-intensive than nonexporters.

Recent contributions in international trade emphasize the fact that most industries

[0]When working on this chapter, I have benefited from comments by Carsten Eckel, Swati Dhingra, Florian Unger, and participants at the IO and Trade Seminar at the University of Munich, the Workshop "Internationale Wirtschaftsbeziehungen" in Goettingen 2013, and the European Trade Study Group in Birmingham 2013.

are dominated by firms that produce more than one product.[1] In this chapter, I address the R&D portfolio of a multi-product firm (MPF), whereby the focus is to analyze separately different types of research. Firms may invest in product innovation and product differentiation, besides investments in production processes. Unbundling these different strands of innovation helps to distinguish between different welfare channels. In contrast to models with single-product firms, where gains from trade originate at the industry-level through entry or exit of firms and "between-firm" reallocations of market shares, I highlight intra-firm adjustments as a source for welfare improvements.

Globalization increases the market but also reinforces competition in these markets. The large literature on heterogeneous firms has shown that the latter effect dominates for low-performing firms. I consider large MPFs, therefore, I focus on the market size effect of globalization. Rising sales volumes in a larger market raise the returns to the different types of innovation through economies of scale. In my model, a firm weighs the marginal benefit of each type of innovation against the fixed up-front development costs and as the marginal benefit of innovating is increasing in the market size, more investments are encouraged.

A main element of my theory are demand linkages stressed in recent contributions to the international trade literature on MPFs (see for instance: Eckel and Neary (2010) and Dhingra (2013)). In these papers, firms internalize a cannibalization effect when introducing additional varieties to their product portfolio. This means, if varieties within an MPF are horizontally differentiated, adding a new product will create a negative demand externality on all other products of this firm. In my framework, the innovating firm can dampen this negative externality of product innovation by investing in the degree of product differentiation. It is natural to assume that the strength of the cannibalization effect depends on the substitutability of products within the product range of a firm. Adding products differing only slightly from each other, will have a strong cannibalizing impact on existing varieties. However, a product range that spans products which are highly differentiated is less susceptible to cannibalization. To avoid cannibalization among products, firms can invest in new

[1]Bernard et al. (2010) report the dominance of MPFs. Although MPFs represent a minority of 39 percent of firms, these firms account for 87 percent of output. In a trade context, Bernard et al. (2007) document for the year 2000 that firms that export multiple products account for 99.6 percent of export value.

blueprints or product specific attributes such as differences in functional features or design. Furthermore, promotion activities such as advertisement or marketing campaigns help to showcase the differences between products. All these measures come along with fixed costs, however, they are implemented to satisfy the consumers' desire to choose from a broad and diversified product range.

The key result of the model is that a larger market or trade cost reductions enhance the profit maximizing product range of an MPF and optimal spending in both product differentiation and process innovation. An MPF that widens its product range loses market shares of its existing products through cannibalization. This makes additional spending in product differentiation worthwhile. Furthermore, sunk costs for product differentiation and process innovation are determined endogenously and depend on the level of investment and not on scale and scope of production. Thus, a rising market size enables firms to exploit economies of scale in innovation and gives rise to increasing optimal investment levels as investment costs can be spread over more units of output. Beyond this, I show that returns to both product differentiation and process innovation do not just depend on the size of the market but also on the efficiency of research input utilization. The Global Innovation Index (2013) reports disparities and persistent innovation differences among regions.[2] This is indicative of differences in the scope for product differentiation and the opportunities to reduce production costs between firms in different industries or in developed and less developed countries. The more efficient research input is transformed into research output, the higher will be the equilibrium investment levels and the larger will be the adjustments to globalization. This insight is important to keep in mind when discussing consumers' welfare in the context of my model.

On the demand side, I specify quadratic preferences à la Melitz and Ottaviano (2008) and compute the indirect utility function as an appropriate measure for welfare. Consumers benefit from more variety (*love of variety*), *lower prices,* and, notably, from the degree of product differentiation. I refer to this property of the utility function as *love of diversity.* The latter means that consumers value a given product range more when products are more differentiated or rephrasing it, the marginal utility of

[2]The Global Innovation Index is published by the business school INSEAD and the World Intellectual Property Organization (WIPO), a specialized agency of the United Nations. It ranks 141 economies on the basis of their innovation capabilities and results.

each newly introduced product is increasing in the degree of product differentiation. Having disentangled these three individual welfare channels, I discuss the gains from trade liberalization arising from intra-firm adjustments. Globalization induces an MPF to enlarge and diversify its product range. Given the *love of variety* and *love of diversity* properties of the utility function, this improves consumer welfare. Furthermore, a larger market is associated with technology upgrading. The resulting cost savings are passed on to consumers, leading to welfare gains from lower prices. However, as indicated above, I show that the gains from trade depend on the efficiency of the investments. Conducting the thought experiment of firms innovating in two different scenarios - a developed and a less developed country -, I argue that trade liberalization will lead to larger welfare improvements when innovation input is converted efficiently in valuable output.

This model is related to the growing trade literature on MPFs with quadratic preferences for differentiated varieties. In Eckel et al. (2011), MPFs invest in the quality of their products. Because of the assumption of flexible manufacturing, firms will invest most in their core product which is sold at the largest scale. Dhingra (2013) analyzes the impact of trade policy on product and process innovation, keeping the degree of product differentiation exogenous. Similar to my model, economies of scale increase optimal spending for process innovation. Separating between internal and external competition, she shows that, in response to trade liberalization, firms will reduce their product range to dampen the cannibalization effect. Firms in my model also try to mitigate cannibalization, however, as I allow for investments in product differentiation, the channel stressed here is a different one.

To model investments in product differentiation, I build on recent contributions with single-product firms by Lin and Saggi (2002), Rosenkranz (2003), and Bastos and Straume (2012). These authors also assume quadratic preferences and derive optimal investment strategies for single-product firms.[3] Firms invest to horizontally differentiate their products from those produced by their rivals. Therefore, the motive for the investment is different in comparison to the multi-product framework presented in this chapter. Lin and Saggi (2002) explicitly point out that in a framework with

[3] Ferguson (2011) proposes a model with monopolistic competition and CES preferences. In his model, single-product firms invest in horizontal product differentiation to differentiate their product from the products of their rivals. Similar to my model, the author investigates how the size of the market affects the extent of endogenous product differentiation.

two single-product firms, investing more in product differentiation also has a negative strategic effect. From a consumer's perspective, also the rival's product seems more differentiated when a firm increases its spending for product differentiation. The resulting increase in the other firm's output hurts the investing firm. Having the same two products produced by one MPF, the MPF internalizes the externality from the investment and, therefore, will differentiate its products more to avoid cannibalization.[4] In a multi-product Dixit-Stiglitz framework, Lorz and Wrede (2009) endogenize the degree of product differentiation.[5] In a notably different theoretical setup, these authors also evaluate how firms respond to globalization in terms of product variety and diversity. However, the focus of my model is different, as I split up the R&D portfolio of an MPF to disentangle the welfare gains from globalization. The remainder of this chapter is organized as follows: In the next section, I present the theoretical model where I start with the optimal consumer behavior in section 3.2.1. Section 3.2.2 introduces the second stage of the model, where a firm decides on its optimal scale and scope of production. In the first stage in section 3.2.3, a firm chooses optimal spending in both product differentiation and process optimization. I assume that the firm perfectly anticipates the outcome of the second stage. In section 3.2.4, I conduct a comparative statics exercise where the focus is on the effects of globalization. Finally, in section 3.2.5, I disentangle the implications of globalization on consumer welfare. Section 3.3 concludes and summarizes results. I provide all mathematical derivations in the Appendix of this chapter in section 3.4.

3.2 The Model

In this part of the model, I introduce a two stage framework of MPFs. In the *first stage*, an MPF chooses its spending on product differentiation and process innovation, anticipating the effects on optimal scale and scope in the following stage. By investing in process innovation, an MPF can simply lower its variable production

[4] In the Appendix of this chapter, I provide a formal analysis for this result. In a simplified version of the main model, I show how the incentives to innovate in product differentiation differ between single-product firms and MPFs.

[5] In the related industrial organization literature, Lambertini and Mantovani (2009) develop a dynamic model of MPFs and investigate whether there exists complementarity or substituability between investments in product and process innovation.

costs. As I have already noted in the introduction, investments in product differentiation imply investing in new blueprints for distinct product features and designs or marketing expenses. These investments make sure that from a consumer's point of view the product portfolio offers a huge variety of unique products. From a firm's perspective, however, these investments are made to reduce cannibalization within its own product range. Both types of investments are costly and require up-front endogenous sunk costs. In the *second stage*, the firm simultaneously chooses the quantity produced of each good and the number of products produced. Production incurs variable costs and a fixed capacity cost for each new production line.

The economy under consideration involves a homogeneous goods industry and a differentiated goods industry. Production in the homogeneous industry is subject to constant returns to scale with a unit cost requirement and there is no contingence of R&D. For the sake of simplicity, I characterize the differentiated industry by one active monopoly MPF.[6]

I begin this section with the analysis of consumer preferences and derive optimal demand. Then, the focus is on the optimal behavior of an MPF in the differentiated industry. Solving the two-stage model via backwards induction, I start deriving optimal scale and scope of the firm. Subsequent, in the first stage of the game, I derive two conditions for optimal spending in product differentiation and process innovation. In a comparative statics exercise, the focus is on the effects of globalization on optimal R&D expenditures. In particular, I investigate how decreasing transport costs or an increasing market size affect optimal firm behavior. The model is rounded down by a section on the gains from trade arising from the within-firm adjustments. For that purpose, I derive the indirect utility function associated with the underlying preference structure and discuss consumer welfare.

[6] I focus on intra-firm adjustments, so competition between firms plays only a second-order role. For an extension of a similar framework to oligopoly, the interested reader is referred to the Appendix in Eckel et al. (2011).

3.2.1 Consumer Behavior: Preferences and Consumer Demand

In the economy under consideration, L consumers maximize their utility defined over the consumption of a homogeneous and a differentiated product. Within the differentiated sector, I further assume that consumers buy a set Ω out of a potential set $\widetilde{\Omega}$ of the differentiated product. The preference structure of a representative consumer follows a quasi-linear specification:[7]

$$U = q_0 + u_1, \tag{3.1}$$

where q_0 is the consumption of the homogeneous good, which is sold at a price $p_0 = 1$. The latter serves as numeraire and absorbs any income effects. Therefore, the following analysis occurs in a partial equilibrium setting. u_1 defines utility in the differentiated sector and displays a standard quadratic form:

$$u_1 = aQ - \frac{1}{2}b\left[(1 - e(s))\int_{i\in\widetilde{\Omega}} q(i)^2 di + e(s)\,Q^2\right]. \tag{3.2}$$

In this specification, a and b represent non-negative preference parameters and $q(i)$ denotes per variety consumption with $i \in \widetilde{\Omega}$. Total consumption by the representative consumer is given by $Q \equiv \int_{i\in\widetilde{\Omega}} q(i)di$. The parameter $e(s) \in [0,1]$ is an inverse measure of product differentiation and is of central interest, as it can be chosen endogenously by a firm. The value of $e(s)$ is determined by the level of investment s that an MPF spends on product differentiation. Further assumptions on $e(s)$ will be discussed later on in the model. At this point, however, it is important to notice that lower values of $e(s)$ imply that products are more differentiated and hence less substitutable. The extreme case of $e(s) = 1$ denotes that consumers have no taste for diversity in products and demand depends on aggregate output only.

Consumers maximize utility subject to the budget constraint $q_0 + \int_{i\in\widetilde{\Omega}} p(i)q(i)di = I$, where $p(i)$ denotes the price for variety i and I is individual income. Utility

[7] These preferences combine the continuum quadratic approach to symmetric horizontal product differentiation of Ottaviano et al. (2002) with the preferences in Neary (2009).

maximization yields the following linear inverse individual demand function

$$\lambda p(i) = a - b\left[(1 - e(s))q(i) + e(s)Q\right], \tag{3.3}$$

where λ is the marginal utility of income, the Lagrange multiplier attached to the budget constraint. Given the quasi-linear upper-tier utility, there is no income effect, thereby implying that $\lambda = 1$. Market-clearing imposes that an MPF faces a market demand $x(i)$ that consists of the aggregated demand of all consumers $Lq(i)$ for variety i. For the inverse market demand, I derive

$$p(i) = a - b'\left[(1 - e(s))x(i) + e(s)X\right], \tag{3.4}$$

where a is the consumers' maximum willingness to pay, $b' \equiv \frac{b}{L}$ is an inverse measure for the market size, and finally, $X \equiv \int_{i\in\Omega} x(i)di$ represents total demand in the differentiated industry. Eq. (3.4) reveals the price $p(i)$, a consumer is willing to pay for variety i, as negatively dependent on a weighted average of the sales of variety i and total output of all available varieties. From Eq. (3.4), I derive direct demand for variety i as

$$x(i) = \frac{a}{b'(1 - e(s) + e(s)\delta)} - \frac{p(i)}{b'(1 - e(s))} + \frac{e(s)\delta\overline{p}}{b'(1 - e(s) + e(s)\delta)(1 - e(s))}, \tag{3.5}$$

where δ describes the mass of consumed varieties in Ω. The average price of differentiated varieties in the economy is given by $\overline{p} = 1/\delta \int_{i\in\Omega} p(i)\,di$.

In the model I present hereafter, a firm can invest in the degree of product differentiation, which affects the cross elasticity between any two varieties. The cross elasticity of variety i with respect to any other variety j is given by:

$$\varepsilon_{i,j} \equiv \left|\frac{\partial x(i)}{\partial x(j)}\frac{x(j)}{x(i)}\right| = \frac{e(s)}{(1 - e(s))}\frac{x(j)}{x(i)}. \tag{3.6}$$

It is straightforward to see that investments in the degree of product differentiation (lower values of $e(s)$) reduce the cross elasticity $\varepsilon_{i,j}$ and hence weaken the strength of the cannibalization effect within a firm's portfolio. The lower is the substitutability between varieties, the less does the output of any additional variety reduce the demand for the other products within the portfolio.[8] From a demand perspective, this is the reason why MPFs will invest in the degree of product differentiation in my model.

Lemma 3.1 *By investing in the degree of product differentiation, an MPF can lower the magnitude of the cannibalization effect through a lower cross elasticity of demand between varieties.*

To conclude this section on preferences, I follow Melitz and Ottaviano (2008) and derive the indirect utility function associated with the quadratic preferences as an appropriate measure for welfare

$$U = I + \frac{\delta}{2b\left(1 - e\left(s\right) + e\left(s\right)\delta\right)}\left(a - \overline{p}\right)^2 + \frac{\delta}{2b\left(1 - e\left(s\right)\right)}\sigma_p^2. \tag{3.7}$$

The term $\sigma_p^2 = \frac{1}{\delta}\int_0^\delta \left(p\left(i\right) - \overline{p}\right)^2 di$ represents the variance of prices. The demand system exhibits "love of variety", as welfare increases in the product range δ, holding $\overline{p}$ and σ_p^2 constant. Furthermore, welfare decreases in the average price and increases in the variance of prices. In section 3.2.5, further important properties of Eq. (3.7) are discussed in detail.

3.2.2 Firm Behavior: Optimal Scale and Scope

I start analyzing the optimal firm behavior at the second stage of the model. The firm's objective in this section is to maximize profits by choosing both the scale and scope of production. By doing this, a firm considers R&D investments as given. I assume a cost function $c\left(i, k\right)$ for producing variety i, which depends on the technology level k the firm has chosen. I further suppose that each MPF has access to a continuum of potential varieties, however, due to a fixed cost for new production

[8] Furthermore, investments in the degree of product differentiation also affect the price elasticity of demand. Referring to Melitz and Ottaviano (2008), I express the price elasticity of demand as $\varepsilon_i \equiv \left|\left(\partial x\left(i\right)/\partial p\left(i\right)\right)\left(p\left(i\right)/x\left(i\right)\right)\right| = p\left(i\right)/\left(p^{\max} - p\left(i\right)\right)$, where $p^{\max} \equiv \frac{(1-e(s))a + e(s)\delta\overline{p}}{(1-e(s)+e(s)\delta)}$ is the choke price of the linear demand system. Investments in the degree of product differentiation affect the choke price and, thus, the price elasticity. For a given average price $\overline{p}$ and product range δ, investments in product differentiation reduce the price elasticity and hence relax the firms' internal "competition" between varieties as: $\frac{\partial p^{\max}}{\partial e}\mid_{\overline{p},\delta=const} = -\frac{\delta(a-\overline{p})}{(1-e(s)+e(s)\delta)^2} < 0$.

lines it does not necessarily produce all of them. Denoting the scope of the product portfolio by δ, total profits are given by

$$\pi = \int_0^\delta \left[p(i) - c(i,k) - t\right] x(i)di - \delta r_\delta, \tag{3.8}$$

where t is a uniform trade cost payable by the firm on all the varieties it sells. r_δ represents the fixed cost the firm has to pay for each new production line. Firms simultaneously choose the quantity produced of each good (optimal scale) and the mass of goods produced (optimal scope).

Optimal Scale Maximizing profits in Eq. (3.8) with respect to $x\left(i\right)$ implies the first-order condition for scale:

$$\frac{\partial \pi}{\partial x(i)} = p(i) - c(i,k) - t - b' \left[(1-e\left(s\right))x(i) + e\left(s\right)X\right] = 0, \tag{3.9}$$

which leads to the optimal output of a single variety

$$x(i) = \frac{a - c(i,k) - t - 2b'e\left(s\right)X}{2b'(1-e\left(s\right))}, \tag{3.10}$$

with $X \equiv \int_0^\delta x\left(i\right)di$ denoting total firm scale.[9] The negative impact of total firm scale X on the output of a single variety displays the cannibalization effect:

$$\frac{\partial x(i)}{\partial X} = -\frac{e\left(s\right)}{\left(1-e\left(s\right)\right)} < 0. \tag{3.11}$$

The strength of the cannibalization effect depends on the substitutability of the varieties within the product portfolio of the firm, i.e. the parameter $e\left(s\right)$. It is easily verified, that the magnitude of the cannibalization effect in Eq. (3.11) is increasing in the value of $e\left(s\right)$.

For the sake of simplicity and without loss of generality, I impose symmetry on the

[9] The second-order condition for this maximization problem is given by: $\frac{\partial^2 \pi}{\partial x(i)^2} = \frac{\partial p(i)}{\partial x(i)} - b'\left(1-e\right) - b'e\frac{\partial X}{\partial x(i)} < 0$.

production costs: $c(i,k) = c(j,k) = c(k)$.[10] Therefore, I rewrite Eq. (3.10) as:

$$x = \frac{a - c(k) - t}{2b'(1 - e(s) + e(s)\delta)}. \tag{3.12}$$

Total firm output is then simply given by:

$$X = \frac{\delta(a - c(k) - t)}{2b'(1 - e(s) + e(s)\delta)}. \tag{3.13}$$

Note that total output X in Eq. (3.13) rises in the product range δ, however, output of each variety x is decreasing in δ due to the cannibalization effect. Put it differently, the relationship between total firm output X and the product range δ is a concave function, whereby the slope depends on the degree of product differentiation $e(s)$. Assuming perfectly differentiated products, i.e. $e(s) = 0$, the relation turns out to be linear.[11]

To derive the optimal price, I combine Eq. (3.12) with the inverse demand function Eq. (3.4) and get:

$$p = \frac{a + c(k) + t}{2}. \tag{3.14}$$

Prices are increasing functions of both production and transportation costs.

Optimal Scope I proceed and consider the firm's choice of its profit maximizing product range. Besides the fixed costs r_δ, the extension of the product portfolio is also limited through the additional cannibalization associated with the launching of further products. I rewrite total profits in Eq. (3.8) as follows

$$\pi = \frac{\delta(a - c(k) - t)^2}{4b'(1 - e(s) + e(s)\delta)} - \delta r_\delta, \tag{3.15}$$

[10] Eckel and Neary (2010) assume a technology that embodies flexible manufacturing. A firm possesses a core competence and marginal costs for any other variety rise in the distance to the core product. The idea that firms posses one core product is also featured in recent models by Arkolakis and Muendler (2010), Qiu and Zhou (2013), and Mayer et al. (2014).

[11] Total firm output X is an increasing function of the product range δ as: $\frac{\partial X}{\partial \delta} = \frac{(1-e(s))(a-c(k)-t)}{2b'(1-e(s)+e(s)\delta)^2} > 0$. The second derivative is negative: $\frac{\partial^2 X}{\partial \delta^2} = -\frac{e(s)(1-e(s))(a-c(k)-t)}{b'(1-e(s)+e(s)\delta)^3} < 0$, which implies a concave relation between the variables X and δ.

where operative profits must be positive, i.e.

$$r_\delta < \frac{(a - c(k) - t)^2}{4b'(1 - e(s) + e(s)\delta)}. \tag{3.16}$$

Maximizing Eq. (3.15) with respect to δ implies the respective first-order condition for scope:[12]

$$\frac{\partial \pi}{\partial \delta} = \frac{(1 - e(s))(a - c(k) - t)^2}{4b'(1 - e(s) + e(s)\delta)^2} - r_\delta = 0. \tag{3.17}$$

From Eqs. (3.12) and (3.13), it follows that per variety output decreases but total firm output increases in additional products. An MPF optimally solves this trade-off and adds new varieties until the marginal return of an additional variety equals the fixed cost r_δ of an investment in additional capacity. From inspection of Eq. (3.17), it is straightforward to see that the marginal return of new varieties is decreasing in the number of products δ. Solving for the optimal product range yields:

$$\delta = \frac{(a - c(k) - t)\sqrt{\left(\frac{(1-e(s))}{b' r_\delta}\right)} - 2(1 - e(s))}{2e(s)}. \tag{3.18}$$

The condition on r_δ stated in Eq. (3.16) ensures that the product range takes positive values. The optimal product range rises with falling fixed costs r_δ and falling variable costs $c(k)$. Furthermore, I am interested in the effects of globalization on the product range of an MPF. In my model, globalization is captured through falling trade costs t or a rising market size L (i.e. lower values of $b' \equiv \frac{b}{L}$). Inspecting Eq. (3.18) reveals the multiplicative structure of the fixed costs for product innovation r_δ and the inverse measure for the market size b'. Therefore, an increase in the market size L has the same effect as decreasing fixed costs r_δ. I interpret the term $b' r_\delta$ as the perceived costs of product innovation which are lower in a larger market.

In the first stage of the model, the firm can invest in the degree of product differentiation. Therefore, it is of further interest how this investment affects the optimal product range of an MPF. It can be shown that a larger scope for product differentiation induces the firm to enlarge its product range δ. The reason for this is that lower

[12]The second-order condition is given by: $\frac{\partial^2 \pi}{\partial \delta^2} = -\frac{e(s)(1-e(s))(a-c(k)-t)^2}{2b'(1-e(s)+e(s)\delta)^3} < 0$.

values of $e(s)$ imply more investments in blueprints for product specific features or marketing, which reduce cannibalization among varieties. These investments create a broader spectrum of technological opportunities within a firm can establish more varieties. I summarize these results in the following proposition.

Proposition 3.1 *Lower values of trade costs t or a larger market size L increase the profit maximizing product range of an MPF, i.e.*

$$\frac{d\delta}{dt} < 0 \text{ and } \frac{d\delta}{dL} > 0. \tag{3.19}$$

Furthermore, a rising degree of product differentiation (lower values of $e(s)$) dampens the cannibalization effect and, hence, induces an extension of the product range, i.e.

$$\frac{d\delta}{de} < 0. \tag{3.20}$$

All derivatives are presented in the Appendix.

3.2.3 Firm Behavior: Optimal R&D Portfolio of an MPF

In this section, I discuss the first stage of the model. I assume that the firm correctly foresees how output levels and product range are determined in the second stage. Firms can invest in cost-reducing process optimization and in a more differentiated product range. To derive the firm's profit function in this stage, I combine the optimal product range in Eq. (3.18) with the gross profits $\widetilde{\pi}$ in Eq. (3.15) and come up with the following expression:

$$\Pi = \widetilde{\pi} - kr_k - sr_s, \tag{3.21}$$

where

$$\widetilde{\pi} = \frac{\left(a - c\left(k\right) - t\right)\left(\left(a - c\left(k\right) - t\right) - 2\sqrt{\left(b' r_\delta \left(1 - e\left(s\right)\right)\right)}\right)}{4b' e\left(s\right)}. \tag{3.22}$$

Recall that k is the level of investment in process optimization and s denotes the investment in product differentiation. Process R&D is conducted at a rate r_k and investing in product differentiation is carried out at a rate r_s. By investing k units in process innovation, a firm can lower its production costs $c(k)$, following the assumptions:

$$\frac{\partial c}{\partial k} \equiv c'(k) < 0 \text{ and } \frac{\partial^2 c}{\partial k^2} \equiv c''(k) > 0. \tag{3.23}$$

The level of product differentiation $e(s)$ is determined by:

$$\frac{\partial e}{\partial s} \equiv e'(s) < 0 \text{ and } \frac{\partial^2 e}{\partial s^2} \equiv e''(s) > 0, \tag{3.24}$$

where $e(0) = 1$ and $e(\infty) = 0$. To ensure interior solutions, I further assume that $e'(0) = c'(0) = -\infty$ and $e'(\infty) = c'(\infty) = 0$. I do not impose any specific functional forms of Eqs. (3.23) and (3.24) to keep the analysis as general as possible. However, the curvatures of $c(k)$ and $e(s)$ are of special interest as they capture the innovation efficiency of firms. To clarify this issue, I determine the elasticity of $c(k)$ and $e(s)$ with respect to innovation inputs k and s as: $\varepsilon_{c(k)} \equiv |d \ln c / d \ln k| \equiv \left| c'(k) \frac{k}{c(k)} \right|$ and $\varepsilon_{e(s)} \equiv |d \ln e / d \ln s| \equiv \left| e'(s) \frac{s}{e(s)} \right|$. According to that, the percentage change of $c(k)$ and $e(s)$ following an one percentage point increase in k or s, respectively, will be larger, the larger are $|e'(s)|$ and $|c'(k)|$. Having this in mind, I can discuss the implications of differences in the ability to innovate between firms in different countries or industries at a very general level.

Figure 3.1: Differences in the Ability to Innovate

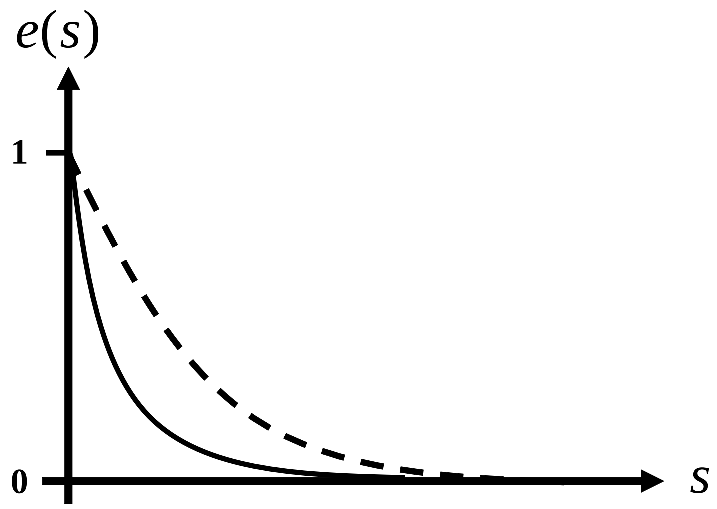


Figure 3.1 illustrates the response of the differentiation parameter e on the investment level s. It is natural to assume that there are differences in the scope for product differentiation between firms, for example, in less developed and developed countries. A certain level of development is necessary to create blueprints for a broad and highly differentiated product range. This is illustrated in Figure 3.1, where the solid line represents a developed country and the dashed line represents a less developed country. The message from the graph is straightforward: Firms in a developed country are more efficient in innovation leading to a higher degree of product differentiation for a given level of investment s.[13] Furthermore, the steeper slope (larger $|e'(s)|$) of the solid line indicates that a marginal unit of innovation input will be transformed into more innovation output in the developed country.[14] I will revisit this point when I study the impact of trade liberalization on the innovation choices and the consequent welfare analysis.

In the first stage, the firm maximizes Eq. (3.21) both with respect to k and s. The first-order conditions for this maximization problem read as follows:

$$\frac{\partial \Pi}{\partial s} = \frac{\partial \widetilde{\pi}}{\partial e} e'(s) - r_s = 0, \tag{3.25}$$

and

$$\frac{\partial \Pi}{\partial k} = \frac{\partial \widetilde{\pi}}{\partial c} c'(k) - r_k = 0, \tag{3.26}$$

where

$$\frac{\partial \widetilde{\pi}}{\partial e} < 0 \text{ and } \frac{\partial \widetilde{\pi}}{\partial c} < 0. \tag{3.27}$$

Operating profits are rising in the degree of product differentiation (lower values of $e(s)$) as this reduces cannibalization and, therefore, lowers competition between the products within the portfolio. Moreover, it is straightforward that operating profits are increasing in lower production costs. The exact expressions for $\frac{\partial \widetilde{\pi}}{\partial e}$ and $\frac{\partial \widetilde{\pi}}{\partial c}$, and

[13] The Global Innovation Index 2013 ranks countries according to their innovation efficiency. Innovation efficiency is calculated as the ratio of the innovation output over innovation input in a country.

[14] Acemoglu and Zilibotti (2001) argue that even if all countries have access to the same set of technologies, there will be large cross-country differences because of varying economic conditions. Their argument is the skill scarcity in developing countries which makes skill-complementary technologies inappropriate. This technology-skill mismatch leads to differences in the efficiency how countries transform innovation inputs into innovation outputs.

a proof that these terms are negative is provided in the Appendix. Furthermore, I provide a simplified version of the model, where I investigate the differences in the incentives to innovate in product differentiation between MPFs and single-product firms.

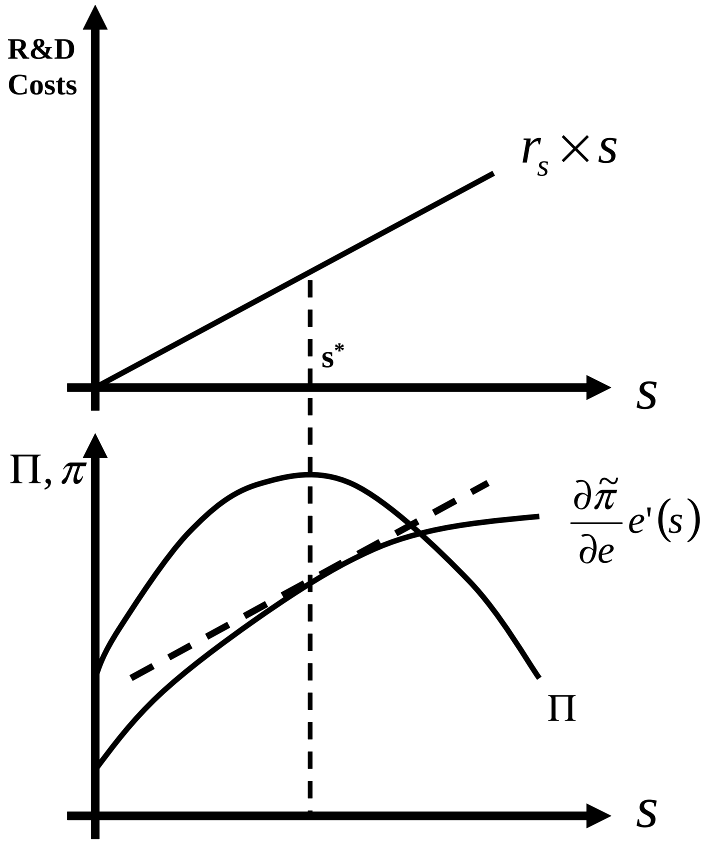
Eqs. (3.25) and (3.26) suggest that the marginal benefits of the two investments essentially consist of two elements. The *first* element is the direct effect of a change in the degree of product differentiation or the cost parameter on the operating profits $\widetilde{\pi}$ demonstrated in Eq. (3.27). Most importantly, the magnitude of the direct effect depends on the firm size. This is related to early findings by Schumpeter, who argued that only firms with sufficiently large sales can cover the high fixed costs associated with R&D projects. The *second* element embodies the responsiveness of the differentiation and the cost parameter with respect to investments: $e'(s)$ and $c'(k)$. According to this, the marginal benefit of an investment also depends on the efficiency of transforming research input into output. The larger $|e'(s)|$ and $|c'(k)|$, respectively, the greater is the impact of the marginal unit of investment.

Lemma 3.2 *The marginal benefit of an investment depends on (i) the total firm size (determined by scale and scope) and (ii) the efficiency of research input utilization.*

The first-order conditions in Eqs. (3.25) and (3.26) suggest that it is optimal to invest in process innovation and product differentiation, respectively, until the marginal benefits equal the marginal costs of the investment.

Figure 3.2 illustrates the optimal behavior for the case of investments in product differentiation. The shape of the marginal benefit curve is concave due to the assumptions made on $e(s)$. The optimal investment level s^* is determined at the point where the slope of the investment cost curve is just equal to the slope of the marginal benefit curve. In this point, total profits Π are maximized. Furthermore, it can be seen in the graph that the equilibrium investment levels s^* and k^* increase in the responsiveness of the functions $e(s)$ and $c(k)$, i.e. in their respective slopes $e'(s)$ and $c'(k)$. Eqs. (3.25) and (3.26) implicitly determine the equilibrium levels of product differentiation $s^* = s^*(k,\ r_s,\ t,\ r_\delta,\ b')$ and process innovation $k^* = k^*(s,\ r_k,\ t,\ r_\delta,\ b')$. In the next section, I present comparative statics results with respect to the variables in brackets.

Figure 3.2: Optimal Degree of Product Differentiation



3.2.4 Comparative Statics

Having characterized the equilibrium R&D levels, I derive several comparative statics results of the model. I start with the effects of an exogenous change in the investment costs (r_s and r_k) and the capacity costs r_δ, followed up with the cross-effects of process innovation on product differentiation and vice versa. Afterwards, the focus is on the effects of economic integration on the equilibrium R&D efforts. As mentioned above, globalization can be captured by both an increase in market size L and a reduction in transportation costs t.

To derive the comparative statics results, I totally differentiate Eqs. (3.25) and (3.26). The explicit mathematical expressions for all derivatives are provided in the Appendix. In the following subsections, I will employ the graphical tool provided in

Figure 3.2 and discuss the results intuitively.

Change in Investment Costs and Capacity Costs It is straightforward to determine the effects of rising innovation costs on the equilibrium levels of s^* and k^*. Rising rates r_s and r_k increase the costs of R&D and, therefore, reduce equilibrium levels of both process innovation and product differentiation. In Figure 3.2, this can be illustrated by a rising slope of the investment cost curve in the upper part of the diagram. Consequently, the optimal investment level is shifted to the left hand side. The effects of varying capacity costs r_δ on the investment levels can be interpreted like the effects of a changing product range. From Eq. (3.18), it follows that rising capacity costs r_δ will reduce the profit maximizing product range. The latter reduces total firm size. Keeping this coherence in mind, it is obvious that rising fixed costs r_δ reduce both the optimal levels of product differentiation and process innovation as the gains from these investments are reduced. More precisely, investments in differentiation are cut back, as within a smaller product range, the cannibalization effect is less fierce. Furthermore, due to a lower firm-level output, the benefits from a better technology level are reduced, leading to less process innovation. Expressed in Figure 3.2, this means a lower slope of the marginal benefit curve, which again shifts the optimal investment level to the left hand side. I summarize these findings in the following proposition.

Proposition 3.2 *Rising investment costs (r_s and r_k) and capacity costs (r_δ) reduce optimal levels of investment in both product differentiation and process innovation, i.e.*

$$\frac{ds^*}{dr_s} < 0; \frac{dk^*}{dr_k} < 0, \tag{3.28}$$

and

$$\frac{ds^*}{dr_\delta} < 0; \frac{dk^*}{dr_\delta} < 0. \tag{3.29}$$

Cross - Effects In the next step, I investigate the interaction between process innovation and product differentiation. As in the related industrial organization literature with single product firms (see for example Lin and Saggi (2002)), I find a two-way complementarity in which the investment in one branch of research makes the other more attractive. On the one hand, Eq. (3.18) shows that a better technology induces an MPF to add more products to its portfolio. The latter intensifies cannibalization and incentivizes a higher level of product differentiation. On the other hand, more differentiated products enable a higher sales volume and, therefore, enhance the incentives to invest in a better technology.

Proposition 3.3 *Firms invest more in product differentiation when they can undertake process innovation and vice versa, i.e.*

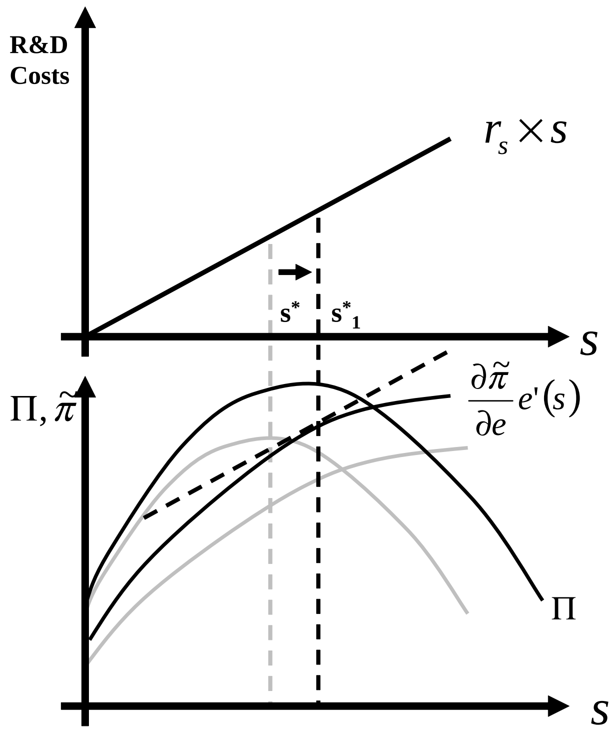
$$\frac{ds^*}{dk} > 0 \text{ and } \frac{dk^*}{ds} > 0. \tag{3.30}$$

Globalization I conclude this section with inspecting the effects of trade liberalization on the R&D efforts of MPFs. In my framework, globalization is modelled as a reduction in trade costs t or alternatively, following Krugman (1979), as an increase in the market size L (recall: the demand parameter $b' \equiv \frac{b}{L}$ is an inverse measure of market size which is decreasing in the number of consumers). Considering proposition 3.1, I know that a larger market encourages a firm to add additional products to its portfolio. An MPF which widens its product range cannibalizes market shares of its existing products. This makes additional spending on product differentiation attractive. At the same time, total firm output X rises after trade liberalization, which raises investments in both product differentiation and process innovation through economies of scale. In Figure 3.3, this is illustrated through a steeper marginal benefit curve, which leads to a higher equilibrium spending on product differentiation s_1^*.[15] Economic integration can also be interpreted as a process of reducing trade costs. Similar to an increase in market size, lower transportation costs enlarge total firm output and induce higher equilibrium investments in both types of R&D.

The fact that investments of firms are positively correlated to the market size is in line with recent contributions in the literature. Lileeva and Trefler (2010) and Bustos (2011) underline how rising revenues after trade liberalization induce exporters to invest in better technologies. Concerning the investment in product differentiation, my findings are related to models with endogenous investments in quality, such as

[15] The same graph could be drawn for process innovation.

Figure 3.3: Economies of Scale in Innovation



Antoniades (2012) for single-product firms and Eckel et. al (2011) for MPFs. In these papers, spending in quality is an endogenous sunk cost and is increasing in firm scale. Firms choose expenditures subject to the size of the market as with more consumption the investment costs can be spread over more units of output.

Studying the impact of trade liberalization on the equilibrium investment levels reveals a coherence between the magnitude of the effects and the efficiency of the investment input utilization. The more efficient are firms in a country or an industry in transforming innovation inputs into innovation outputs, i.e. the larger are $|e'(s)|$ and $|c'(k)|$, the larger is the magnitude of the effects of globalization. I summarize these results in the following proposition.

Proposition 3.4 *Rising market size L and falling trade costs t enhance the equilibrium levels of both types of investments, i.e*

$$\frac{ds^*}{dL} > 0; \frac{dk^*}{dL} > 0, \tag{3.31}$$

and

$$\frac{ds^*}{dt} < 0; \frac{dk^*}{dt} < 0. \tag{3.32}$$

The magnitude of these effects is amplified when innovation inputs are in efficient use.

3.2.5 Welfare

This section builds on the comparative static results concerning globalization and studies the impact on consumer welfare. Following Melitz and Ottaviano (2008), the indirect utility stated in Eq. (3.7) serves as an appropriate measure for welfare. In the simplified model setup with symmetric varieties, indirect utility is reduced as follows:

$$V = I + \frac{\delta}{2b\left(1 - e\left(s\right) + e\left(s\right)\delta\right)}\left(a - p\right)^2. \tag{3.33}$$

I start the welfare analysis by discussing important properties of the indirect utility function in Eq. (3.33). By doing this, I identify the distinct channels through which innovation affects consumers' welfare. Having unbundled the different welfare channels, I focus again on the variables concerning globalization and discuss the welfare gains from trade liberalization.

Properties of the Indirect Utility Function At a first glance and not strikingly, welfare is higher the lower is the price level p. Furthermore, as already mentioned, the indirect utility function displays "love of variety", i.e.

$$\frac{\partial V}{\partial \delta}\mid_{p,e=const} = \frac{\left(1 - e\left(s\right)\right)}{2b\left(1 - e\left(s\right) + e\left(s\right)\delta\right)^2}\left(a - p\right)^2 > 0. \tag{3.34}$$

For a given price and degree of product differentiation, consumer welfare is increasing in the number of available products δ. As the degree of product differentiation is endogenously chosen by a firm in my model, I am interested in the role of product differentiation for consumer welfare. It is straightforward to show that the marginal utility of an additional product is increasing in the degree of product differentiation:

$$\frac{\partial V}{\partial \delta \partial e} = -\frac{\left(2 - e\left(s\right)\right)\delta - \left(1 - e\left(s\right)\right)}{2b\left(1 - e\left(s\right) + e\left(s\right)\delta\right)^3}\left(a - p\right)^2 < 0. \tag{3.35}$$

Furthermore, I can show that for a given product range δ, utility is increasing when products are more differentiated:[16]

$$\frac{\partial V}{\partial e}\mid_{p,\delta=const}=-\frac{\delta\left(\delta-1\right)}{2b\left(1-e\left(s\right)+e\left(s\right)\delta\right)^{2}}\left(a-p\right)^{2}<0. \tag{3.36}$$

I call this attribute of the utility function "love of diversity". In addressing the question to what extent globalization matters for consumer welfare in my framework, this property of the utility function is central. From previous discussion, it is obvious that consumers value a given product range more when products are more differentiated.

Lemma 3.3 *Welfare increases in the number of available products ("love of variety"), the degree of product differentiation ("love of diversity"), and decreases in the price level.*

Welfare Gains from Trade With the properties of the welfare function fully characterized, I proceed discussing some of the key implications of the theory. In the previous section, I have analyzed the impact of trade liberalization on the product range and the endogenous choice of R&D expenditures. I recap the key comparative statics results and highlight their implications for consumer welfare.
My theoretical model suggests an extension of the product range following an increase in the market size or alternatively lower trade costs. Qualitatively, this result is in line with trade models with single-product firms such as Krugman (1980) and Melitz (2003) where the transition from autarky to trade induces entry of firms. Firm entry increases the number of available products in the market, which gives rise to gains from trade through the well-known "love of variety" nature of the utility function. However, worthwhile to mention at this point is the different source of gains from trade in this model stemming from adjustments within the firm in contrast to entry of firms at the industry level.

[16] Welfare gains have diminishing returns with respect to product differentiation: $\frac{\partial V^2}{\partial^2 e}\mid_{p,\delta=const}=\frac{\delta(a-p)^2(\delta-1)^2}{b(1-e(s)+e(s)\delta)^3}>0$. Substituting information from Eqs. (3.4) and (3.12) in the indirect utility Eq. (3.33), I compute the total derivative as follows: $\frac{dV}{de}=\frac{(a-c(k)-t)^2}{8b([(1-e(s)+e(s)\delta)])^2}\left(\left(1-e\left(s\right)\right)\frac{d\delta}{de}-\delta\left(\delta-1\right)\right)<0$. Recall from proposition 3.1 that $\frac{d\delta}{de}<0$.

The endogenous choice of investment levels in product differentiation and process innovation is the key element of this theory. Trade liberalization enables firms to exploit economies of scale in innovation and increases incentives to invest in R&D as in a larger market fixed investment costs can be spread over a larger scale of output. Therefore, my formal analysis reveals increasing spending in both types of investments after trade liberalization. This enhances welfare via two separate channels. The central welfare channel in this model is what I called "love of diversity". Given the opportunity to serve a larger market, an MPF will spend more resources on research for new blueprints or product specific attributes. For the consumer, this increases welfare as it leads to products with new functional features or a new design and thus the opportunity to choose from a broader product range. Technically, a higher degree of product differentiation enlarges the marginal utility of each new product and thus enhances welfare. Furthermore, consumers enjoy lower prices as MPFs increase investments in better processes. As firm size grows in a larger market, a better technology becomes more valuable. The resulting cost savings are passed on to consumers, leading to welfare gains from lower prices (compare Eq. (3.14)). To unbundle the different channels analytically, I substitute Eqs. (3.4) and (3.12) into Eq. (3.33) and rewrite the indirect utility function as follows:

$$V = I + \frac{\delta \left(a - c\left(k\right) - t\right)^2}{8b\left[\left(1 - e\left(s\right) + e\left(s\right)\delta\right)\right]}. \tag{3.37}$$

By totally differentiating Eq. (3.37), I identify the three distinct channels which were discussed above. The following expression represents the gains from trade induced by an increase in the market size L:[17]

$$\frac{dV}{dL} = \underbrace{\frac{\left(1 - e\left(s\right)\right) bx^2}{2L^2}\frac{d\delta}{dL}}_{>0\text{: Love of variety}} \underbrace{-\frac{2b\left(\delta - 1\right)\left(a - c\left(k\right) - t\right)X}{L} e'\left(s\right)\frac{ds}{dL}}_{>0\text{: Love of diversity}} \underbrace{-\frac{X}{2L}c'\left(k\right)\frac{dk}{dL}}_{>0\text{: Lower prices}} > 0. \tag{3.38}$$

Inspection of Eq. (3.38) clearly reveals that consumers in a larger market are better off. It highlights three distinct channels of gains from trade and shows how trade liberalization affects welfare through within-firm adjustments. I derive the analogous

[17] To determine the sign of the derivative in Eq. (3.38), recall that $e'(s) < 0$ and $c'(k) < 0$. Furthermore, it follows from proposition 3.1: $\frac{d\delta}{dL} > 0$ and from proposition 3.4: $\frac{ds}{dL} > 0$ and $\frac{dk}{dL} > 0$.

expression for falling trade costs t in the Appendix.
Preceding discussion suggested that consumers in a larger market or in a market with lower trade costs, ceteris paribus, are better off. The magnitude of the gains from trade naturally depends on the increase of investment levels after trade liberalization. Furthermore, inspection of Eq. (3.38) reveals that the welfare gains also depend on the efficiency of research input utilization determined by $e'(s)$ and $c'(k)$. If trade induced investments (i.e. $\frac{ds}{dL}$ and $\frac{dk}{dL}$) do not generate more differentiated products or a better production technology because of inefficient innovation (low values of $|e'(s)|$ and $|c'(k)|$), the welfare gains from an increase in the market size will be low. The latter implies that gains from trade will be larger in a developed country where due to better technological conditions the marginal benefit of each unit of investment is higher. I summarize these results in the following proposition.

Proposition 3.5 *Table 3.1 summarizes the welfare gains from trade integration through the different elements of the welfare function. Economies of scale after trade liberalization lead to larger welfare gains in countries where the technological stage of development allows an efficient use of research input.*

Table 3.1: Welfare Effects of Globalization

Effects of $L \uparrow$ or $t \downarrow$:	Welfare channel:
Product range: $\delta \uparrow$	Love of variety
Product differentiation: $s^* \uparrow$; $e(s) \downarrow$	Love of diversity
Process innovation: $k^* \uparrow$; $c(k) \downarrow$	Lower prices

3.3 Conclusion

In this chapter, I focus on the gains from trade associated with intra-firm adjustments. There is indeed recent evidence that innovating firms account for a large fraction of the productivity and variety gains at a sector-level. To distinguish between the different welfare channels, I construct a multi-product framework in which a firm invests in different types of research. Trade liberalization provides welfare gains, which originate at the firm-level because firms exploit economies of scale in innovation. An MPF weighs the marginal benefit of each type of innovation against the fixed up-front development costs. The market size effect of globalization accompanied by rising sales volumes raises the returns to the different types of innovation. Consumers benefit from a larger product portfolio (love of variety) of more differentiated products (love of diversity). Furthermore, a larger firm output encourages technology-upgrading. Consumers benefit from the investment in a cost-reducing technology through lower prices.

The key element of this theory is the investment in the degree of product differentiation and the consequent welfare gains through more differentiated products. In most studies, product differentiation is a main component of the industry structure, which is treated as an exogenous variable. By endogenizing the degree of product differentiation, I highlight an additional channel in which globalization may affect product variety. I show that adding additional products in a larger market encourages MPFs to invest in a more diversified product range. In contrast to single-product firms, MPFs have higher incentives to invest in product differentiation in order to reduce the cannibalization effect. Consumers enjoy additional gains as the marginal benefit of any new variety rises in the degree of product differentiation. This implies that consumer welfare is not only determined by the absolute number of available products but by the individual product features that distinguish these varieties. Consumers value choosing from a broad and diversified product range. Therefore, investments in the diversity of the available products is an important aspect when analyzing consumer welfare. Finally, I have shown that welfare improvements through economies of scale depend on the efficiency of innovation input utilization. The better research input is transformed into research output, the higher will be the equilibrium investment levels and the larger will be the gains from trade through intra-firm adjustments.

3.4 Appendix

3.4.1 Proof of Proposition 3.1

In the model presented above, globalization is captured by lower trade costs t or a larger market size L (lower values of b'). Though it is straightforward to see the effects of globalization on firm scope in Eq. (3.18), I present the derivatives for completeness. Differentiating Eq. (3.18) with respect to t and b' yields:

$$\frac{d\delta}{dt} = -\frac{\sqrt{\left(\frac{(1-e(s))}{b' r_\delta}\right)}}{2e(s)} < 0, \tag{3.39}$$

and

$$\frac{d\delta}{db'} = -\frac{(a - c(k) - t)\sqrt{\left(\frac{(1-e(s))}{b' r_\delta}\right)}}{4b' e(s)} < 0. \tag{3.40}$$

The second part of proposition 3.1 considers the effect of the degree of product differentiation on the optimal product range. Differentiating Eq. (3.18) with respect to $e(s)$ yields:

$$2\delta \frac{d \ln \delta}{d \ln e} = -\left(\frac{(a - c(k) - t)}{2}\sqrt{\left(\frac{1}{b' r_\delta (1 - e(s))}\right)} + 2(\delta - 1)\right) < 0. \tag{3.41}$$

3.4.2 Optimal Firm Behavior in the First Stage

Maximizing Eq. (3.21) with respect to s and k leads to the first-order conditions in Eqs. (3.25) and (3.26). The explicit expressions for $\frac{\partial \widetilde{\pi}}{\partial e}$ and $\frac{\partial \widetilde{\pi}}{\partial c}$ in Eq. (3.25) are given by

$$\frac{\partial \widetilde{\pi}}{\partial e} = -\frac{(a - c(k) - t)\left(\delta - \frac{1}{2}\right)}{2e(s)}\sqrt{\left(\frac{r_\delta}{b'(1 - e(s))}\right)} < 0, \tag{3.42}$$

and

$$\frac{\partial \widetilde{\pi}}{\partial c} = -\frac{(a - c(k) - t) - \sqrt{(b' r_\delta (1 - e(s)))}}{2b' e(s)} < 0. \tag{3.43}$$

To derive Eq. (3.42), differentiate $\widetilde{\pi}$ in Eq. (3.22) with respect to $e(s)$ and substitute information from Eq. (3.18).

3.4.3 Comparative Statics

In this part of the Appendix, I provide all analytical results for section 3.2.4. To derive my results, I totally differentiate the following first-order conditions:

$$\frac{\partial \Pi}{\partial s} = -\frac{(a - c(k) - t)\left((a - c(k) - t) - (2 - e(s))\sqrt{\left(\frac{b' r_\delta}{(1-e(s))}\right)}\right)}{4b' e(s)^2} e'(s) - r_s = 0, \tag{3.44}$$

and

$$\frac{\partial \Pi}{\partial k} = -\frac{(a - c(k) - t) - \sqrt{(b' r_\delta (1 - e(s)))}}{2b' e(s)} c'(k) - r_k = 0. \tag{3.45}$$

Throughout the analysis, I apply the following second-order conditions:

$$\frac{\partial^2 \Pi}{\partial s^2} = \frac{\partial^2 \widetilde{\pi}}{\partial e^2} e'(s) + \frac{\partial \widetilde{\pi}}{\partial e} e''(s) < 0, \tag{3.46}$$

and

$$\frac{\partial^2 \Pi}{\partial k^2} = \frac{\partial^2 \widetilde{\pi}}{\partial c^2} c'(k) + \frac{\partial \widetilde{\pi}}{\partial c} c''(k) < 0. \tag{3.47}$$

To determine the signs of the following derivatives, recall that $e'(s) < 0$ and $c'(k) < 0$.

Proof of Proposition 3.2 The following derivatives show how equilibrium investment levels s^* and k^* respond to changes in investment and capacity costs.

Change in Investments Costs:

$$\frac{ds^*}{dr_s} = \frac{1}{\frac{\partial^2 \Pi}{\partial s^2}} < 0 \tag{3.48}$$

$$\frac{dk^*}{dr_k} = \frac{1}{\frac{\partial^2 \Pi}{\partial k^2}} < 0 \tag{3.49}$$

Change in Capacity Costs:

$$\frac{ds^*}{dr_\delta} = -\frac{(a - c(k) - t)\left((2 - e(s))\sqrt{\left(\frac{b'}{r_\delta(1-e(s))}\right)}\right)}{8b'e(s)^2\frac{\partial^2\Pi}{\partial s^2}}e'(s) < 0 \tag{3.50}$$

$$\frac{dk^*}{dr_\delta} = -\frac{1}{4e(s)\frac{\partial^2\Pi}{\partial k^2}}\sqrt{\left(\frac{(1-e(s))}{b'r_\delta}\right)}c'(k) < 0 \tag{3.51}$$

Proof of Proposition 3.3 To determine the interaction between process innovation and product differentiation (cross-effects), I totally differentiate Eq. (3.44) with respect to k and Eq. (3.45) with respect to s. I combine the derivatives with information from Eq. (3.18) to show the positive signs.

$$\frac{ds^*}{dk} = -\frac{e'(s)c'(k)}{2b'e(s)\frac{\partial^2\Pi}{\partial s^2}}\left(\frac{(a-c(k)-t)}{2e(s)} + \sqrt{\left(\frac{b'r_\delta}{(1-e(s))}\right)}\left(\delta - \frac{1}{2}\right)\right) > 0 \tag{3.52}$$

$$\frac{dk^*}{ds} = -\frac{e'(s)c'(k)}{2b'e(s)\frac{\partial^2\Pi}{\partial k^2}}\left(\frac{((a-c(k)-t))}{2e(s)} + \sqrt{\left(\frac{b'r_\delta}{(1-e(s))}\right)}\left(\delta - \frac{1}{2}\right)\right) > 0 \tag{3.53}$$

Proof of Proposition 3.4 Globalization is captured by an increase in the size of the market L (recall: $b' \equiv \frac{b}{L}$) or by falling trade costs t. The following derivatives show how equilibrium values of s^* and k^* respond to changes in these parameters.

Change in Market Size: Again, I totally differentiate Eq. (3.44) and then substitute information from Eq. (3.18) to show that the sign of the following derivative is clearly negative:

$$\frac{ds^*}{db'} = -\frac{(a-c(k)-t)}{4b'^2e(s)\frac{\partial^2\Pi}{\partial s^2}}\left(\frac{(a-c(k)-t)}{2e(s)} + \delta\sqrt{\left(\frac{b'r_\delta}{(1-e(s))}\right)}\right)e'(s) < 0. \tag{3.54}$$

From inspection of Eq. (3.22), I know that the following expression is clearly negative:

$$\frac{dk^*}{db'} = -\frac{2\left(a - c\left(k\right) - t\right) - \sqrt{\left(b' r_\delta \left(1 - e\left(s\right)\right)\right)}}{4b'^2 e\left(s\right) \frac{\partial^2 \Pi}{\partial k^2}} c'\left(k\right) < 0. \tag{3.55}$$

Change in Trade Costs:

$$\frac{ds^*}{dt} = -\frac{e'\left(s\right)}{2b' e\left(s\right) \frac{\partial^2 \Pi}{\partial s^2}} \left(\frac{\left(\left(a - c\left(k\right) - t\right)\right)}{2e\left(s\right)} + \sqrt{\left(\frac{b' r_\delta}{\left(1 - e\left(s\right)\right)}\right)} \left(\delta - \frac{1}{2}\right) \right) < 0 \tag{3.56}$$

$$\frac{dk^*}{dt} = -\frac{c'\left(k\right)}{2b' e\left(s\right) \frac{\partial^2 \Pi}{\partial k^2}} < 0 \tag{3.57}$$

3.4.4 Welfare

In the main body of this chapter, I present the disentangled welfare gains of an increase in the market size L. For the sake of completeness, I also present the explicit expression for a change in the trade cost parameter t.

$$\frac{dV}{dt} = \underbrace{\frac{\left(1 - e\left(s\right)\right) x^2 b}{2L^2} \frac{d\delta}{dt}}_{<0\text{: Love of variety}} \underbrace{- \frac{2b\left(\delta - 1\right)\left(a - c\left(k\right) - t\right) X}{L} e'\left(s\right) \frac{ds}{dt}}_{<0\text{: Love of diversity}} \underbrace{- \frac{X}{2L}\left(1 + c'\left(k\right)\frac{dk}{dt}\right)}_{<0\text{: Lower prices}} < 0 \tag{3.58}$$

3.4.5 A Benchmark Model with Two Products and Endogenous Product Differentiation

In this part of the Appendix, I formulate a simplified version of the model with only two varieties being produced. These varieties are offered by either two single-product firms that compete in a Cournot fashion or by one MPF. Using this simple model, I want to show how the incentives to innovate in the degree of product differentiation differ according to whether the two products are offered by one MPF or by two single-product firms. As the focus is on innovation in product differentiation, I abstract from the two other strands of R&D considered in the main model. The following executions will be held rather scarce as the model presented here is based on the model in the main body.

Preferences As in the main model, the preference structure of a representative consumer follows a quasi-linear specification:

$$U = q_0 + a\left(q_1 + q_2\right) - \frac{1}{2} b\left(q_1^2 + q_2^2 + 2e\left(s\right) q_1 q_2\right), \tag{3.59}$$

where $e\left(s\right) \in [0, 1]$ and q_0 is the consumption of the homogeneous good. The specification in Eq. (3.59) is the two goods case equivalent to the preference structure in the main model. Utility maximization gives rise to the following market demand system:

$$p_1 = a - b'\left(x_1 + e\left(s\right) x_2\right) \text{ and } p_2 = a - b'\left(x_2 + e\left(s\right) x_1\right), \tag{3.60}$$

where market-clearing imposes that: $x_1 \equiv Lq_1$ and $x_2 \equiv Lq_2$. As I am not interested in market size effects, I assume in the following that $b = L = 1$.

Optimal Firm Behavior I consider two scenarios in this section. In the first scenario, two firms, each producing one variety, invest in the degree of product differentiation. In the second scenario, an MPF produces the two varieties and conducts the investment. In both scenarios, the marginal cost of production equals c and r_δ denotes the fixed capacity cost. As in the main model, firm i can invest s units in the degree of product differentiation $e\left(s\right)$. The investments follow the assumptions made in Eq. (3.24). Again, investments in the degree of product differentiation are conducted at a rate r_s.
As it has already been pointed out by Lin and Saggi (2002), for Cournot firms, investments in the degree of product differentiation have two conflicting effects on profits. For the profits of firm i, this means

$$\frac{d\pi_i}{ds_i} = \underbrace{\frac{\partial \pi_i}{\partial e} e'\left(s_i\right)}_{\text{Direct effect: } >0} + \underbrace{\frac{\partial \pi_i}{\partial x_j}\frac{dx_j}{\partial e} e'\left(s_i\right)}_{\text{Indirect effect: } <0}. \tag{3.61}$$

The direct effect in Eq. (3.61) is positive. It captures the increase in the demand for the own product following investments in the degree of product differentiation. However, there is also a negative indirect effect from the investment. This strategic effect occurs because also firm j benefits from the investment of firm i. The resulting increase in the output of the competing firm j hurts the innovating firm i. The latter effect displays the crucial difference to the case of an MPF. An MPF internalizes the strategic effect as it produces both varieties. Therefore, it will invest more in product differentiation as, on the one hand, it can increase output of both varieties and, on the other hand, the cannibalization effect across the two varieties is dampened. Obviously, the positive effect of investments in product differentiation on product innovation that was mentioned in proposition 3.1 cannot occur here as the number of products is exogenously given.

Equilibrium Investment Levels in the Two Scenarios In the case of two single-product firms, profits of firm i in the second stage are given by

$$\pi_i = (p_i - c)\, x_i - r_\delta. \tag{3.62}$$

The demand system in Eq. (3.60), implies the following equilibrium profits under Cournot competition:

$$\pi_i = \left(\frac{(a-c)}{(2+e(s))}\right)^2 - r_\delta. \tag{3.63}$$

In the R&D stage, total profits of firm i are given by:

$$\Pi_i = \pi_i - s_i r_s. \tag{3.64}$$

The respective first-order condition for this maximization problem is

$$\frac{\partial \Pi_i}{\partial s_i} = \frac{\partial \pi_i}{\partial e} e'(s_i) - r_s = 0, \tag{3.65}$$

where $\frac{\partial \pi_i}{\partial e} = -\frac{2(a-c)^2}{((2+e(s)))^3} < 0$ and $e'(s_i) < 0$.
In the second scenario, the two products are offered by one MPF. The profits of the firm in the second stage are given by:

$$\pi = (p_1 - c)\, x_1 + (p_2 - c)\, x_2 - 2r_\delta. \tag{3.66}$$

Calculating the equilibrium profits yields:

$$\pi = \frac{(a-c)^2}{2(1+e(s))} - 2r_\delta. \tag{3.67}$$

In the R&D stage, the firm maximizes the following profit function

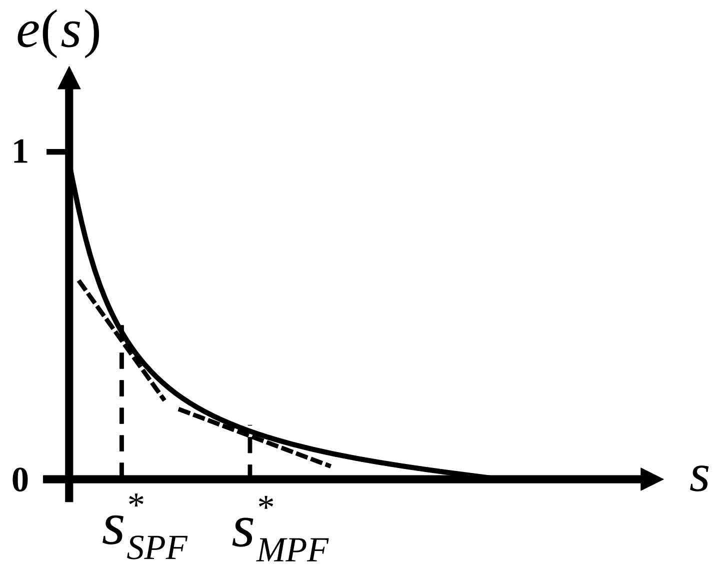
$$\Pi = \pi - sr_s, \tag{3.68}$$

with respect to an optimal investment level s. The first-order condition is given by

$$\frac{\partial \Pi}{\partial s} = \frac{\partial \pi}{\partial e} e'(s) - r_s = 0, \tag{3.69}$$

where $\frac{\partial \pi}{\partial e} = -\frac{(a-c)^2}{2((1+e(s)))^2} < 0$.

Figure 3.4: Optimal Degree of Product Differentiation: MPF vs. SPF



Eqs. (3.65) and (3.69) implicitly determine the optimal investments for the two scenarios. From inspection of these equations, one observes that an MPF will invest more in the degree of differentiation as $\left|\frac{\partial \pi}{\partial e}\right|_{MPF} > \left|\frac{\partial \pi}{\partial e}\right|_{SPF}$. Since $((2+e(s)))^3 > 4((1+e(s)))^2$ for all $e(s) \in [0,1]$, it follows that the marginal benefit for product differentiation is higher for MPFs. The latter implies that in the optimum:

$|e'(s)|_{MPF} < |e'(s)|_{SPF}$. Figure 3.4 illustrates again the properties of the function $e(s)$ and helps with the interpretation of the result.

Lemma 3.4 *Even in the case of an exogenous product range of two products, MPFs will invest more in the degree of product differentiation than single-product firms. For a single-product firm, the marginal benefit of the investment is lower, as the investment is accompanied by a negative strategic effect. An MPF internalizes this effect as it produces both varieties. Therefore, it will invest more in product differentiation as, on the one hand, it can increase output of both varieties and, on the other hand, the cannibalization effect across these two varieties is dampened.*

Conclusion

This thesis aims to contribute to the novel literature on MPFs in international trade. It was motivated by recent empirical observations which document the dominant role of MPFs in both domestic and international businesses. An overwhelming share of international activity is performed by large firms which manufacture a broad variety of products. For these firms, the trend towards more integrated world markets gives rise to new opportunities. The main focus of this thesis was in particular on two issues: Offshoring and the positive impacts of larger markets on innovation activity. Both aspects have received a lot of attention in the international trade literature, however, almost exclusively in the context of models considering single-product firms. Therefore, the aim of my thesis was to establish novel results on the offshoring and innovation behavior of MPFs, which I hope, will contribute to a better understanding of how firms behave in global markets.

Whilst writing this thesis, I tried to focus on explaining issues which are specific to MPFs and, therefore, cannot be explained in models based on single-product firms. This conclusion is not a place where I want to repeat all findings, however, I will draw some inferences that are common to all three chapters. In all three essays, I emphasized changes in the product range of a firm as an important margin of adjustment to globalization. Since the seminal work of Krugman (1979), product variety has played a central role in many models belonging to the new trade theory. In several passages of this thesis, I have stressed the importance of within-firm product expansion for the total number of available varieties in an economy. Therefore, analyzing the product range of MPFs and understanding the determinants, which may have an influence on it, is a crucial aspect to have in mind when analysing the variety gains from international trade.

One of the main results of Chapter 1 was that offshoring has a positive impact on the product range of a firm. A firm which has the opportunity to relocate entire production lines of labor-intensive products will extend its portfolio by new products. Importantly, these varieties are produced in the offshore destination and would not be offered by the firm in the case of solely domestic production. This type of offshoring brings forth novel labor market implications (the cannibalization effect of offshoring), however, it was shown that even with endogenous factor prices and lower domestic wages following a reduction in offshoring costs, the positive impact of offshoring on the product range remains stable. This points to a so far unexplored channel through which globalization can increase product variety and thus stimulate welfare. Therefore, this chapter may also be a springboard for future empirical research that could quantify the effects of offshoring on the product portfolio of firms.

Chapters 2 and 3 focused on the innovation behavior of MPFs in global markets. Using Brazilian firm-level data, Chapter 2 reveals that firms have increased their investment efforts in product innovation following an increase in the market size. In the underlying theoretical model, this result was explained by economies of scale and the lower perceived costs of product innovation in a larger market. Facing a larger market potential, firms are willing to spend more on R&D, which increases their product offering. A further result of this chapter was that the returns to product innovation are determined by the degree of product differentiation in a sector. Empirically, we found that firms in industries with a low scope for product differentiation will invest less in new products. Our theoretical framework revealed one reason for this behavior. It was shown that due to the stronger cannibalization effect in a homogeneous sector, the incentive to invest in new products is lower. Chapter 3 picked up this idea and provided a framework in which an MPF could increase the returns to product innovation by investing in the degree of product differentiation within its portfolio. By endogenizing the degree of product differentiation, Chapter 3 highlights an additional channel in which globalization may affect product variety. Allowing for this kind of investment provides novel insights into the welfare gains from variety. On the one hand, additional investments in the degree of differentiation mitigate the cannibalization effect and, therefore, increase the optimal product range of a firm. On the other hand, consumer welfare is not only determined by the absolute number of available products but by the individual product features that distinguish these varieties. Consumers value choosing from a broad and diversified product range. Therefore, investments in the diversity of the available products is an important aspect when analyzing consumer welfare.

Of course, the adaptation of firms to globalization has many different dimensions and I cannot provide a comprehensive picture of all possible channels in this dissertation. Moreover, the frameworks presented throughout the different chapters rely on several simplifying assumptions, which help to focus on the central issues and, at least partly, are made to keep the analysis tractable. However, I hope that my thesis contributes to a better understanding of how firms adjust to globalization and promotes further research on MPFs in the international trade literature. With the availability of better and better firm-level data as well as further theoretical proceedings, this strand of research can be expected to generate many new and interesting insights into the microeconomic behavior in global markets.

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