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## PRODUCT VERSUS PROCESS: INNOVATION STRATEGIES OF MULTI-PRODUCT FIRMS

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## Abstract

We investigate the effects of better access to foreign markets on innovation strategies of multi-product firms in industries with different scope for product differentiation. Industry-specific demand and cost linkages induce a distinction between the returns to innovation. In differentiated industries, cannibalization is lower and firms invest more in product innovation. In homogeneous industries, firms internalize intra-firm spillovers and invest more in process innovation. Using firm-level data and large exchange rate devaluations, we show that better access to foreign markets increases the incentive to innovate. However, we exploit differential effects across industries and show that the innovation strategies depend on the scope of differentiation.



JEL Classification: F12, F14, L25

Keywords: multi-product firms, innovation, product differentiation, Cannibalization Effect, Spillovers, Market Size Effect.



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# Product versus Process: Innovation Strategies of Multi-Product Firms*

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March 13, 2017

**Abstract**

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# 1 Introduction

Successful manufacturing firms continuously innovate to maintain their position in the market and to address consumers' demand. Recent contributions in the international trade literature emphasize the importance of intra-firm adjustments through innovation when explaining welfare gains from trade liberalization, in addition to the well-established intra-industry gains from the entry and exit of firms. This literature highlights innovation as a new dimension in the relationship between exporting and productivity; better access to foreign markets encourages firms to invest in more sophisticated manufacturing technologies, which increases productivity.[1] Consequently, innovation 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 the new products of entering firms but in particular 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 portion of the aggregate changes in industry-level productivity and product variety (Bernard et al. (2010), Broda and Weinstein (2010), Lileeva and Trefler (2010), Bustos (2011)). With the exception of Dhingra (2013) (which is discussed later in detail), innovation in trade models happens in only 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 varying potential implications in terms of welfare gains within industries.

The contribution of the paper is to investigate, theoretically and empirically, the innovation strategies of MPFs focusing on within-firm adjustments. An increase in market size increases the incentives for firms to invest in innovation. However, demand and cost linkages induce a trade-off between product and process innovation. Crucially, such linkages are only

[1] Lileeva and Trefler (2010) as well as Bustos (2011) show 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, access to larger markets induced firms to increase their engagement in product innovation. For Argentinean firms, Bustos (2011) finds an increase in innovation expenditures between 0.20 and 0.28 log points following the average reduction in Brazil's tariffs.

[2] Doraszelski and Jaumandreu (2013) show that for Spanish firms, 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 in a four-year period, 82 percent of product creation happens within existing firms. Only 18 percent of total household expenditure is spent on products of entering firms.

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 unclear a priori.

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 one hand, firms internalize demand linkages by introducing new products that may reduce demand for its own varieties. On the other hand, as a novel feature of our model, firms may internalize intra-firm spillover effects between production lines by investing in process innovation. To understand the role played by the degree of differentiation in this mechanism, consider two firms in sectors with a dissimilar 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. However, investments in process-optimizing technologies may generate a larger return since the benefits from spillover effects across production lines are larger. With similar production processes, the knowledge learned in the production process of more homogeneous products is applicable to a large fraction of the entire product portfolio. For firms in highly differentiated industries, the mechanism works in an opposite fashion.[4]

Our theoretical model builds on Eckel and Neary (2010) and Eckel et al. (2015). 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.[5] However, our theory introduces several novel features. *First*, we explicitly allow for two types of R&D. We assign fixed costs to additional products to model the decision on optimal scope, which is closer to the notion of product innovation.[6] *Second*, firms can invest in product-specific process innovation. Process innovation is costly and reflects economies of scale such that firms invest more in large-scale varieties that are 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 identified as 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

[4]The trade-off between different types of innovation could be intensified by credit constraints. An extent literature has suggested that credit constraints affect the composition of investment over the business cycle. For examples, see Aghion et al. (2010) and Garicano and Steinwender (2016).

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

[6]In our framework, we always refer to product innovation as an increase in product scope.

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 both product and process innovation. Since process innovation reflects economies of scale, access to a larger market promotes technology upgrading. This access to larger markets reduces the perceived costs of product innovation, which encourages MPFs to extend their product scope. (2) 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 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 and provide novel predictions to the empirical literature on innovation and trade. The data has two distinctive features. *First*, we can exploit detailed information on innovation investments by firms over the years 1998-2005. *Second*, large exchange rate devaluations, and in particular the event of a major and unexpected exchange rate devaluation in January 1999, provide an important source of exogenous variation. For Brazilian exporters, the currency devaluation made their 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 in 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 the 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 place more investment in process innovation. Our results are robust to different measures of the degree of differentiation, hold for various estimation strategies (we estimate the incidence of innovation using probit and linear probability model), and remain stable when adding several control variables. Because we are interested in within-firm effects over time, we work only with incumbent firms so that we can identify the effects in a difference-in-differences approach. For further research questions, future research could evaluate a framework with innovation and firm entry.

Our paper is closely related to the literature on MPFs in international trade that features a cannibalization effect.[7] Our theory builds on Eckel et al. (2015), who incorporated an endogenous investment in product quality in the framework by Eckel and Neary (2010). We abstain 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 in MPFs.[8] 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 an instance of trade liberalization, firms face higher competition from foreign firms and 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 abstract from competition and build a framework with demand and cost linkages to evaluate the heterogeneous responses of firms in different industries.[9] The key difference in the way we model innovation with respect to Dhingra (2013) is that we allow for linkage effects on the cost side. We introduce flexible manufacturing and further allow for spillovers in process innovation. Since the strength of the linkage effects depends on the degree of differentiation, our model is able to generate novel predictions across industries regarding the two types of innovation. Hence, the focus of our paper is on the differential effects across industries with a varying scope for differentiation. Using detailed firm-level data, we provide novel empirical results in accordance with the predictions from the model.

Our paper is also related to the literature emphasizing the complementarity between the market size and innovation behavior of firms. 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 homogeneous firm setting. At the firm-level, several papers have investigated the relationship 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 the responses of Canadian plants to the elimination of U.S. tariffs, they find that the more the plants are affected by the tariff cuts, the more they increase their

[7]Eckel and Neary (2010) and Dhingra (2013) introduce cannibalization effects. However, this feature is not considered in many recent MPF models that assume monopolistic competition. One exception is the model proposed by Feenstra and Ma (2008).

[8]Atkeson and Burstein (2010) model endogenous innovation decisions in a general equilibrium setting. They also analyze product and process innovations, but in a framework of single-product producers. Atkeson and Burstein (2010, p. 479) argue "we have ignored the effects that a change in trade costs might have on product innovation by incumbent firms. Consideration of process and product innovation in models with multiproduct firms would be an important extension of our work here."

[9]We abstract from competition to keep the model closer to the empirical analysis, where we evaluate exporter responses to large devaluations that increased market access without increasing competition.

investments in innovation. Lopresti (2016) examines the response of MPFs to the Canada-US free trade agreement of 1989.[10] The paper documents differential responses among firms depending on their involvement in foreign markets. Firms that are less oriented towards export markets reduce their product diversification as trade costs fall, whereas firms with a large share of international sales tend to increase product scope. Yeaple (2005), Verhoogen (2008), and Aw et al. (2011) investigate further channels that relate market size with firm-level innovation and within-firm adjustments.[11]

Another mechanism between trade and innovation is documented by literature which shows that R&D activities are also affected by rising import competition from foreign firms. Using Mexican plant-level data, Teshima (2008) finds that firms increase investments in process R&D following a reduction in output tariffs. Bloom et al. (2016) show that Chinese import competition has led to more innovation within affected firms. Finally, Steinwender (2015) disentangles the effects of market size and import competition on the innovation behavior of firms. While her paper shows large and significant effects of export opportunities on R&D, the impact of import competition is documented as small and insignificant.

# 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 weigh the returns to innovation against the costs. The returns to innovation are in the focus of this paper 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 developing 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 2.1. In this part, we show how the demand linkages enter our framework

[10] This response to the Canada-US free trade aggreement is also analyzed in Baldwin and Gu (2009) as well as Liu (2010).

[11] The literature has also documented product and process innovations as important drivers for the internationalization process of firms. For German data, Becker and Egger (2013) find a higher probability of export for firms that invest in both new products as well as processes. However, their results suggest a dominant role of product innovation relative to process innovation. The important role of product innovation as a determinant of firms' exporting decisions is also documented in Cassiman and Martinez-Ros (2007), as well as Van Beveren and Vandenbussche (2010).

and relate to the degree of product differentiation in a sector. In section 2.2, we present the firm side of the model. We start with the production cost function, which is characterized by flexible manufacturing. Firms can undertake investments in process innovation to reduce the 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 as the degree of product differentiation increases. Firms consider both linkages when maximizing their profits. Finally, section 2.3 derives the equilibrium of the model and establishes the main testable predictions from the theory.

## 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 $\Omega$ of goods from a potential set $\widetilde{\Omega}$ of the differentiated product. Our specification of preferences follows Eckel et al. (2015), though we add an additional numeraire good and assume a quasi-linear utility in the following form:[12]

$$U = q_0 + u_1, \tag{1}$$

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

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

where $a$ and $b$ represent non-negative preference parameters. In this specification, $q(i)$ denotes the per variety consumption and $Q \equiv \int_{i\in\widetilde{\Omega}} q(i)di$ stands for the 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 by 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

[12]The preferences in Eckel et al. (2015) capture an additional component addressing the utility which accrues from consuming goods of higher quality.

later 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:[13]

$$p(i) = a - b'\left[(1-e)y(i) + eY\right]. \tag{3}$$

We define $\Omega \subset \widetilde{\Omega}$ as the subset of varieties which is actually consumed. $y(i)$ describes the market demand for variety $i$ and consists of the aggregated demand of all consumers $Lq(i)$ for that specific variety. $Y \equiv \int_{i\in\Omega} y(i)di$ 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

$$y(i) = \frac{a}{b'(1-e+e\delta)} - \frac{1}{b'(1-e)}p(i) + \frac{e\delta}{b'(1-e+e\delta)(1-e)}\overline{p}, \tag{4}$$

where $\delta$ describes the measure of consumed varieties in $\Omega$. 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 $\varepsilon_{i,j} \equiv |(\partial y(i)/\partial y(j))(y(j)/y(i))| = ey(j)/(1-e)y(i)$. It is straightforward to see that for given output levels, $\varepsilon_{i,j}$ is higher in more homogeneous sectors. For a firm this means that the closer the substitutability between its varieties, the more the output of any additional variety reduces the demand for the other products within the portfolio (i.e. the stronger the demand linkages are within 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 the paper 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 share. 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

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

linear demand system in Eq. (3), there exists an upper bound of the price, where demand $y(i)$ is driven to zero:

$$p^{\max} \equiv \frac{(1-e)\,a + e\delta\overline{p}}{(1-e+e\delta)}. \tag{5}$$

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

$$\varepsilon_i \equiv \left|\frac{\partial y\,(i)}{\partial p\,(i)}\frac{p\,(i)}{y\,(i)}\right| = \frac{p\,(i)}{(p^{\max}-p\,(i))}, \tag{6}$$

by combining Eqs. (4) and (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 $\varepsilon_i$ increases when products become more homogeneous.

$$\frac{\partial p^{\max}}{\partial e}\;|_{\overline{p},\delta=const} = -\frac{\delta\,(a-\overline{p})}{(1-e+e\delta)^2} < 0. \tag{7}$$

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

## 2.2 Firm Behavior: Optimal Product and Process Innovation

In this section, we consider technology and optimal firm behavior. We rely on the monopoly case, for three main reasons. First, we focus on intra-firm adjustments, and therefore competition between firms plays only a second-order role.[14] Second, the vast majority of firm investments happen within existing firms (see Bernard et al. (2010) and Broda and Weinstein (2010) for product innovation and Doraszelski and Jaumandreu (2013) for process innovation) and hence, we abstract from firm entry. Third, in the empirical part of the paper, we investigate data on firm adjustments following exchange rate devaluations for incumbent firms. Large exchange rate devaluations lead to better access to foreign markets without increasing competition.[15] Our way of writing the theory is motivated by deriving

[14]The model could be extended to the oligopoly case. See the Appendix in Eckel et al. (2015). We are interested in cannibalization effects and thus we cannot carry out our analysis in a setting of monopolistic competition, since the latter excludes demand linkages, which are crucial in our framework. Dhingra (2013) analyzes cannibalization in monopolistic competition, as she introduces brands that consist of a set of varieties subject to demand linkages. To model within-brand cannibalization like this, we would need a second substitutability parameter in our preference structure (see the utility function in Dhingra (2013)). However, to remain close to our empirical part, where we use information on the degree of differentiation at the industry-level, we do not include brands in our framework.

[15]Note that all firms in our sample are exporters. Hence, if anything, these firms face less competition in the domestic market and have better access to foreign markets.

predictions that can directly be addressed in the empirical analysis.

We construct a theoretical model in which MPFs optimally choose between two types of investments. Firstly, firms invest in new product lines and thereby extend their product portfolio. Secondly, firms may decide how much to invest in production technology for each of their products. 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. The more similar the products are within the portfolio, the stronger the cannibalization effect of the marginal variety will be. Consequently, we show that the optimal product range will be smaller in a more 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 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. We also 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 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

$$\theta(e) \in (0;1) \text{ with } \theta'(e) > 0. \tag{8}$$

$\theta(e)$ is a key parameter of our model which captures the idea that more homogenous products also imply more similar production processes. Therefore, product specific investments are more applicable to the entire product portfolio in a more homogenous sector, leading to higher investment spillovers between similar products. We will define a functional form for this parameter later in the analysis. In the second part of the paper, we relate an empirical measure of flexibility of the production process to the degree of differentiation. The correlations shown in Table 3 provide empirical support for the theoretical assumption in Eq. (8).

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

$$c(i) = c + c_1 i - \left(2k(i)^{0.5} + 2\theta(e) K_{-i}\right). \tag{9}$$

This can be rearranged to

$$c(i) = c + c_1 i - \left(2(1-\theta(e)) k(i)^{0.5} + 2\theta(e) K\right), \tag{10}$$

where in analogy to $Y$, $K = \int_0^\delta k(i)^{0.5}\, di$ denotes total investment in process innovation.[16]

**Profit Maximization** In our setup, an MPF simultaneously chooses optimal scale $y(i)$ and process innovation $k(i)$ per product as well as optimal product scope $\delta$. Process innovation is carried out at cost $r_k$ and product innovation requires building a new production line whichs costs $r_\delta$. Total profits are given by:

$$\pi = \int_0^\delta \left[p(i) - c - c_1 i + 2(1-\theta(e)) k(i)^{0.5} + 2\theta(e) K\right] y(i) di - \int_0^\delta r_k k(i)\, di - \delta r_\delta. \tag{11}$$

**Optimal Scale** Maximizing profits in Eq. (11) with respect to scale $y(i)$ implies the following first-order condition:[17]

$$\frac{\partial \pi}{\partial y(i)} = p(i) - c - c_1 i + 2(1-\theta(e)) k(i)^{0.5} + 2\theta(e) K - b'(1-e) y(i) - b' e Y = 0. \tag{12}$$

[16] The cost structure is the main distinction to the multi-product framework by Dhingra (2013). Since the focus of our paper is on linkage effects specific to MPFs, we introduce a flexible manufacturing technology that generates linkages on the production side as well as spillovers in processes that capture linkages from innovation activities.

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

Using the inverse demand in Eq. (3) and solving for $y(i)$ yields optimal scale of variety $i$:

$$y(i) = \frac{a - c - c_1 i + 2\left(1 - \theta(e)\right) k(i)^{0.5} + 2\theta(e) K - 2b'eY}{2b'(1-e)}. \tag{13}$$

Furthermore, we derive total firm scale $Y$ by integrating over $y(i)$ in Eq. (13):

$$Y = \frac{\delta\left(a - c - c_1 \frac{\delta}{2}\right) + 2\left(1 - \theta(e) + \theta(e)\delta\right) K}{2b'(1 - e + e\delta)}. \tag{14}$$

Inspection of Eq. (13) reveals two opposing linkage effects arising from the degree of product differentiation in a sector. On one hand, there is a demand linkage (cannibalization) of the firm's total scale $Y$ on the output of a single variety

$$\frac{\partial y(i)}{\partial Y} = -\frac{e}{1-e} < 0, \tag{15}$$

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

$$\frac{\partial y(i)}{\partial K} = \frac{\theta(e)}{b'(1-e)} > 0. \tag{16}$$

As a result of the underlying cost structure with flexible manufacturing, the 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 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 in the analysis.

Substituting optimal scale in Eq. (13) into the inverse demand gives the optimal pricing schedule with the lowest price charged for the core product:

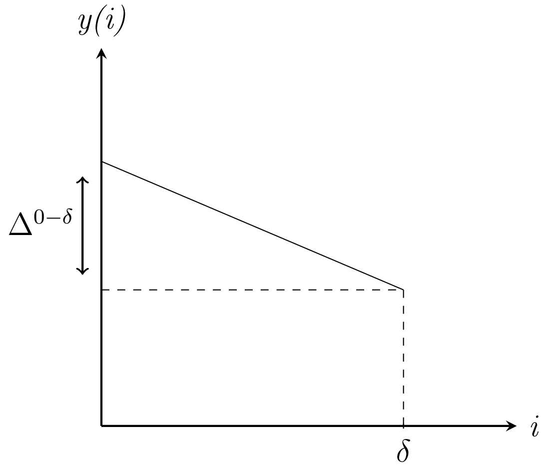
$$p(i) = \frac{1}{2}\left[a + c + c_1 i - 2\left(1 - \theta(e)\right) k(i)^{0.5} - 2\theta(e) K\right]. \tag{17}$$

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:

$$p(i) - c(i) = \frac{a - c - c_1 i + 2\left(1 - \theta(e)\right) k(i)^{0.5} + 2\theta(e) K}{2}. \tag{18}$$

**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

Figure 1: Output Schedule




costs plus indirect savings from spillovers on other products are equal to the rate of innovation costs $r_k$:

$$\frac{\partial \pi}{\partial k(i)} = (1-\theta(e))\, k(i)^{-0.5}\, y(i) + \theta(e)\, k(i)^{-0.5}\, Y - r_k = 0. \tag{19}$$

Solving for optimal investments in variety $i$ yields:[18]

$$k(i) = \left(\frac{(1-\theta(e))\, y(i) + \theta(e)\, Y}{r_k}\right)^2. \tag{20}$$

Eq. (20) shows that optimal investment reflects economies of scale through per variety output $y(i)$ and total firm output $Y$. Given that the output of the core variety is the highest, a firm will put the most effort into optimizing the production process of this variety.[19] However, the first-order condition in Eq. (20) 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 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.*

Finally, we substitute Eq. (13) into Eq. (20) and integrate over the expression. This

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

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

gives total firm investment in process innovation

$$K \equiv \int_0^\delta k(i)^{0.5} \, di = \frac{(1-\theta(e))\,\delta\left(a - c - c_1\frac{\delta}{2}\right) + 2b'(\theta(e) - e)\delta Y}{2\left(b' r_k(1-e) - (1-\theta(e))\left(1-\theta(e)+\theta(e)\,\delta\right)\right)}. \tag{21}$$

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

$$\frac{\partial \pi}{\partial \delta} = [p(\delta) - c(\delta)]\, y(\delta) + \left(-b' e y(\delta) + 2\theta(e)\, k(\delta)^{0.5}\right) Y - r_k k(\delta) - r_\delta = 0, \tag{22}$$

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 (cannibalization) and the positive externality (spillovers in process innovation) on all other products.[20]

$$\underbrace{[p(\delta) - c(\delta)]\, y(\delta)}_{\text{Revenue}} + \{\underbrace{(-b' e y(\delta))}_{\text{Cannibalization}} + \underbrace{\left(2\theta(e)\, k(\delta)^{0.5}\right)}_{\text{Spillover}}\} Y = \underbrace{r_\delta + r_k k(\delta)}_{\text{Inn. Costs}} \tag{23}$$

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. (23). The term "Spillover" in Eq. (23) 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 that determines the net effect of the two linkages.

**Condition 1** *In Eq. (23), 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. Therefore, we restrict the parameters as follows:*

$$b' r_k > \frac{2\theta(e)\left((1-\theta(e))\, y(\delta) + \theta(e)\, Y\right)}{e y(\delta)}. \tag{24}$$

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

[20] To derive the first-order condition for scope in Eq. (22), we derive the following derivative: $\frac{\partial \pi}{\partial \delta} = [p(\delta) - c(\delta)]\, y(\delta) + \int_0^\delta \frac{\partial (p(i) - c(i))}{\partial \delta} y(i)\, di - r_k k(\delta) - r_\delta = 0$. The second-order condition is given by: $\frac{\partial^2 \pi}{\partial \delta^2} = \left[-c_1 - 2\left(b' e y(\delta) - 2\theta(e)\, k(\delta)^{0.5}\right)\right] y(\delta) < 0$. To see that this condition is negative as required, consider Condition 1.

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 is 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 $y(\delta)$. To do so, we substitute the output of the marginal variety from Eq. (13) and its respective price-cost margin from Eq. (18) into the first-order condition for scope (22):

$$y(\delta) = \sqrt{\frac{r_k k(\delta) + r_\delta - 2\theta(e)\, k(\delta)^{0.5}\, Y}{b'(1-e)}}. \tag{25}$$

Considering again Figure 1, the latter expression can be interpreted as follows: The lower the output of the marginal variety $\delta$, the larger the product range offered by the firm.

To provide further insights into our model, we combine the first-order conditions for scale and scope in Eqs. (13) and (25) to derive an alternative expression for optimal scale:

$$y(i) = \frac{c_1(\delta - i) + 2(1-\theta(e))\left(k(i)^{0.5} - k(\delta)^{0.5}\right)}{2b'(1-e)} + \sqrt{\frac{r_k k(\delta) + r_\delta - 2\theta(e)\, k(\delta)^{0.5}\, Y}{b'(1-e)}}. \tag{26}$$

It is straightforward to see that this expression boils down to Eq. (25) 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 $\delta$, illustrated in Figure 1:

$$\Delta^{0-\delta} = \frac{c_1 \delta}{2\left(b'(1-e) - \frac{(1-\theta(e))^2}{r_k}\right)}. \tag{27}$$

Since the underlying technology is flexible manufacturing, the difference in output increases in the product range $\delta$. The larger the distance to the core product, the lower 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 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 investments in the high-scale core varieties.

**Lemma 2** *The difference in scale between the core and the marginal variety is determined by the difference in the production costs of the two varieties. The productivity of the marginal* *product falls with distance from the core product and rises in the degree of spillovers.*

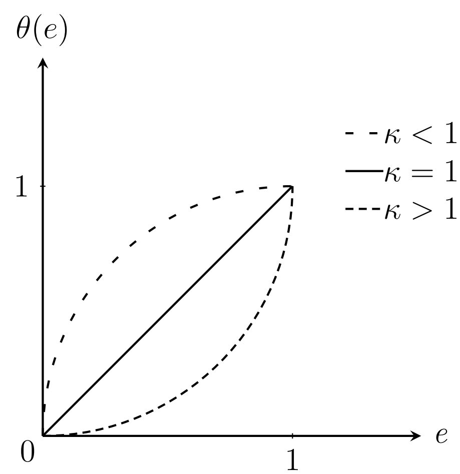
## 2.3 Comparative Statics

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 begin, we analyze the effects of an increase in market size $L$ (lower values of $b'$) on optimal investment levels. We investigate optimal investment strategies in sectors with varying 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 $Y$ and $\delta$ only. As already mentioned, we define a functional form for the spillover parameter $\theta(e)$:

$$\theta(e) = e^{\kappa}. \tag{28}$$

Figure 2 illustrates this functional form and the role of $\kappa$ in determining the strength of spillovers.

Figure 2: Spillover Parameter




Since $e \in [0, 1]$, lower values of $\kappa$ translate into a stronger spillover effect. In the extreme case of $\kappa = 0$, the total investment in one variety is applicable on all varieties within the firm. Obviously, we derive the same result in an industry with no product differentiation (i.e. $e = 1$). Letting $\kappa$ grow larger decreases the importance of spillovers within the firm.

**Equilibrium** In this section, we derive the equilibrium equations of the model by applying the functional form of spillovers in Eq. (28). Combining Eqs. (14) and (21), we derive total firm scale as:

$$Y = \frac{\delta\left(a - c - c_1 \frac{\delta}{2}\right)}{2\left(b'(1 - e + e\delta) - \frac{(1-e^{\kappa}+e^{\kappa}\delta)^2}{r_k}\right)}. \tag{29}$$

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 $Y$. Clearly, the strength of the latter effect is mitigated by the costs of process innovation $r_k$. Plugging Eq. (29) back into Eq. (21) yields total process innovation as:

$$K = \frac{(1 - e^{\kappa} + e^{\kappa}\delta)}{r_k} Y. \tag{30}$$

The parameter $\kappa$ determines the strength of spillovers, where total process innovation is the largest for $\kappa = 0$. Inspecting Eqs. (29) and (30) in detail reveals that investments in process innovation decrease with rising levels of $\kappa$, i.e. $\frac{\partial K}{\partial \kappa} < 0$. Process innovation $K$ reflects economies of scale as it depends on total firm scale $Y$. Using information from Eqs. (20), (29), and (30) together with Eq. (13), we can express optimal scale per variety as:

$$y\,(i) = \frac{a - c - c_1 i - 2\left(b'e - \frac{e^{\kappa}(2(1-e^{\kappa})+e^{\kappa}\delta)}{r_k}\right)Y}{2\left(b'(1-e) - \frac{(1-e^{\kappa})^2}{r_k}\right)}. \tag{31}$$

Within our framework, we have two opposing effects of total scale $Y$ on per variety output. On 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 1 as stated in Eq. (24) guarantees that the spillover effect cannot dominate the cannibalization effect, i.e. $\frac{\partial y(i)}{\partial Y} < 0$.

Finally, substituting from Eq. (20) into Eq. (25), we express the first-order condition for scope as:

$$y\,(\delta) = \sqrt{\frac{r_\delta - \frac{(e^{\kappa}Y)^2}{r_k}}{\left(b'\,(1-e) - \frac{(1-e^{\kappa})^2}{r_k}\right)}}. \tag{32}$$

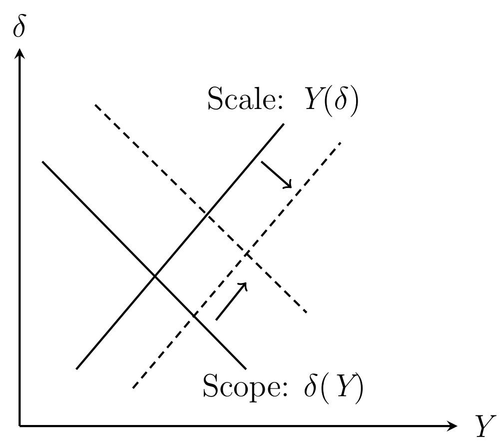
The formal derivation of this expression is presented in the Appendix. Eq. (32) implicitly defines product scope $\delta$ in terms of the output of the marginal variety. Solving for $\delta$ gives the explicit expression for product scope:

$$\delta = \frac{a - c - 2\sqrt{\left(b'\,(1-e) - \frac{(1-e^{\kappa})^2}{r_k}\right)\left(r_\delta - \frac{e^{2\kappa}Y^2}{r_k}\right)} - 2\left(b'e - \frac{2e^{\kappa}(1-e^{\kappa})}{r_k}\right)Y}{\left(c_1 - \frac{2e^{2\kappa}Y}{r_k}\right)}. \tag{33}$$

Eqs. (32) and (33) reveal that higher costs for product innovation $r_\delta$ decrease the optimal product range. The latter implies a higher output of the marginal variety $\delta$ (see Eq. (32)). Referring to Figure 1, this characterizes a variety closer to the firm's core competence. Inspecting the term $2\sqrt{\cdot}$ in Eq. (33) reveals the multiplicative structure of the inverse measure for market size ($b' \equiv \frac{b}{L}$) and the cost for product innovation $r_\delta$. 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: $\delta$ and $Y$. In Figure 3, Eq. (29) is labeled by "Scale: $Y(\delta)$" and describes a positive relationship between total firm output $Y$ and scope $\delta$. Through adding additional products, an MPF can increase its total output. Eq. (33) establishes a negative relationship between $Y$ and $\delta$. The downward-sloping curve "Scope: $\delta(Y)$" 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.

Figure 3: Equilibrium




In the intersection of both curves in Figure 3, the two equilibrium conditions for scale and scope are satisfied.[21] Once we have determined the equilibrium values of $\delta$ and $Y$, we compute the equilibrium value of process innovation $K$. In the next step, we derive the main testable predictions from the model.

**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

[21] 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.

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 large devaluations 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. (3). In the Appendix, we derive the total derivatives of the equilibrium conditions in terms of scale $Y$ (Eq. (29)) and scope $\delta$ (Eq. (33)), which lead to the following results.

We show that increases in the market size lead to higher total firm output $Y$. 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 $Y$. We show that a firm will invest in new products in a larger market, despite cannibalization being intensified through the larger $Y$. In Figure 3, both curves "Scale: $Y(\delta)$" and "Scope: $\delta(Y)$" are shifted to the right, though "Scope: $\delta(Y)$" shifts more. The cannibalization effect of increasing firm scale $Y$ on scope $\delta$ can be visualized by comparing the product range before and after the shift of "Scale: $Y(\delta)$". Technically the increase in product scope is caused by the fact that in Eq. (33) the costs for product innovation $r_\delta$ 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 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. (30), we see that the rise in $\delta$ and $Y$ causes more spending in process innovation. Captured by the term $\frac{(1-e^{\kappa}+e^{\kappa}\delta)^2}{r_k}$ in Eq. (29), the process innovation effect contributes to the rise in firm scale $Y$. We summarize the market size effect on optimal firm behavior in the following proposition and test these results in the empirical part of the paper.

**Proposition 1** *A larger market size $L$ increases total scale $Y$ and induces firms to invest more in both product $\delta$ and process innovation $K$, i.e.*

$$\frac{d\ln Y}{d\ln L} > 0,\ \frac{d\ln \delta}{d\ln L} > 0,\ \textit{and}\ \frac{d\ln K}{d\ln L} > 0. \tag{34}$$

The mathematical derivation of these results is presented in the Appendix. Moreover, 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. In the Web Appendix, we provide a model extension where we introduce an exchange rate into our main framework.

We show that the effect of a devaluation works qualitatively as an increase in market size.

**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 much more scope for differentiation in the latter. 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. (30) with respect to the degree of product differentiation $e$ keeping firm size fixed confirms our intuition:

$$\frac{\partial \ln K}{\partial \ln e} = \frac{\kappa e^{\kappa} (\delta - 1)}{(1 - e^{\kappa} + e^{\kappa}\delta)} > 0. \tag{35}$$

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 the more homogeneous bricks. The more differentiated two cars are, the lower the number of identical parts used in production and the lower the spillovers in production. However, for a firm producing multiple cars, the negative externality of adding an additional car declines when the degree of differentiation is higher (i.e. the cannibalization effect is lower). Again, we hold firm size fixed and differentiate Eq. (33) 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 $\delta$. On one hand, the marginal product cannibalizes but on the other hand, all initial products benefit from process-spillovers of the marginal product. Differentiating Eq. (33) 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.

$$\lim_{\kappa \to 0} \frac{\partial \ln \delta}{\partial \ln e} = -\frac{b' e \left(2Y - y(\delta)\right)}{\left(c_1 - \frac{2Y}{r_k}\right)\delta} < 0 \tag{36}$$

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 of the paper.

**Proposition 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.*

# 3 Data

We test the main predictions of the model using Brazilian firm-level data over the period 1998-2005. 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 surveys from PINTEC (Brazilian Firm Industrial Innovation Survey) conducted every two years with Brazilian firms (with exception of the survey in 2003, for which the time lag refers to three years). 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 major and largely unexpected exchange rate devaluations in the period under analysis. The devaluations made Brazilian products more competitive in both domestic and foreign markets and 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 in the industry. While more homogeneous industries have a higher incentive to invest 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.

## 3.1 Innovation Variables

The innovation surveys provide detailed information on the innovation investments of 2,080 manufacturing exporters for which we can exploit information for the entire period (and 2,320 firms if we estimate an unbalanced panel). 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*). Using this information, we create the variables $Product_{ft} = 1$ if a firm $f$ in industry $i$ reported product innovation (zero otherwise), and $Process_{ft} = 1$ if the firm reported process innovation (zero otherwise). Over the years under analysis, firms are asked every two years about their innovation behavior over the period with exception of the year 2003, for which the time lag refers to 3 years. Hence, in the empirical analysis $t$ refers to the years of the survey.

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. Hence, in order to get closer to our theoretical mechanism we use a question from the surveys related to product scope: 3. Importance of the innovation to increase product scope, $Scope_{ft}$. This categorical variable (with four degrees of importance) relates innovation to increases in product scope. We transform this variable in a dummy $Scope_{ft} = 1$ if the firm reports that it was important or very important to increase scope (and zero otherwise).

We introduce an additional measure that captures the idea of spillovers in process innovation. In particular, we use the following question from the surveys: 4. Importance of the innovation to increase production flexibility, $Flexibility_{ft}$. $Flexibility_{ft}$ 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. We transform this variable in a dummy as described in Table A7 in the Appendix. The measure is consistent with the theoretical model in predicting that firms internalize intra-firm spillover effects. A key assumption of the model is that spillover effects across production lines depend on the degree of product differentiation (see Eq. (8)). To support this assumption, in the empirical analysis we relate $Flexibility_{ft}$ to our empirical measures of the degree of differentiation (see correlations in Table 3). However, one drawback of this variable is that in the model, flexibility is an exogeneous measure rather than an outcome variable. Thus, the regression coefficients should be interpreted with caution.

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.

Besides the availability of panel data, one important advantage of this specific survey is the fact that firms are obliged by law number 5,534 to report information to the Statistical Office, which reduces concerns with non-response. The survey is conducted solely for statistical purposes and the information is strictly confidential, which also implies that firms have less incentive to misreport information. Although the sample is representative, the data has the disadvantage that it covers only 2,080 firms for which we have information over the entire period. More details on the innovation survey are provided in the Data Appendix A.5.

Table 1 presents summary statistics for the main indicators of innovation over the period under analysis. About half of the exporters reported changes in process innovation and 42 percent reported changes in product innovation over the period. Although the variation across firms is in all cases larger, we observe substantial variation within the firm over the period which is crucial for our analysis.

Table 1: Summary Statistics for the Innovation Variables over the Period

| Variable | Mean | Std. Dev. | between variation | within variation |
|---|---|---|---|---|
| $Product_{ft}$ | 0.419 | 0.493 | 0.412 | 0.272 |
| $Process_{ft}$ | 0.507 | 0.499 | 0.399 | 0.306 |
| $Scope_{ft}$ | 0.348 | 0.432 | 0.405 | 0.250 |
| $Flexibility_{ft}$ | 0.384 | 0.482 | 0.402 | 0.155 |

## 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 surveys 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 on 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 ($\lambda_p^{MAX}$) and minimum quality ($\lambda_p^{MIN}$) within a product $p$, as follows: $\lambda_p = \lambda_p^{MAX} - \lambda_p^{MIN}$. In this specification, $\lambda_p$ denotes the difference between the minimum and maximum of the estimated quality $\lambda_{pct}$ of a country $c$'s exports to the United States at time $t$ in product $p$. The higher $\lambda_p$, 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. (6) and (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 $\lambda_s$, 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, which are not traded in an organized exchange but have a quoted reference price, such as industry publications; and **n**, differentiated goods which are without a 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. 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 $s$.[22]

We use $\lambda_s$ as our benchmark measure, since $\lambda_s$ provides a higher variation in comparison to $ShDiff_s$. While $\lambda_s$ 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 use the Rauch (1999) classification for robustness checks. Summary statistics for both measures of differentiation are shown in Table 2.

Table 2: Degree of Product Differentiation by Industry

| Measures of $(1-e)_s$ | Observations | Mean | Std. Deviation | Min | Max |
|---|---|---|---|---|---|
| $\lambda_s$ | 2,080 | 1.74 | 0.18 | 1.10 | 2.27 |
| $ShDiff_s$ | 2,080 | 0.73 | 0.12 | 0.38 | 1 |

## 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 4 shows the evolution of nominal and real exchange rates until the end of

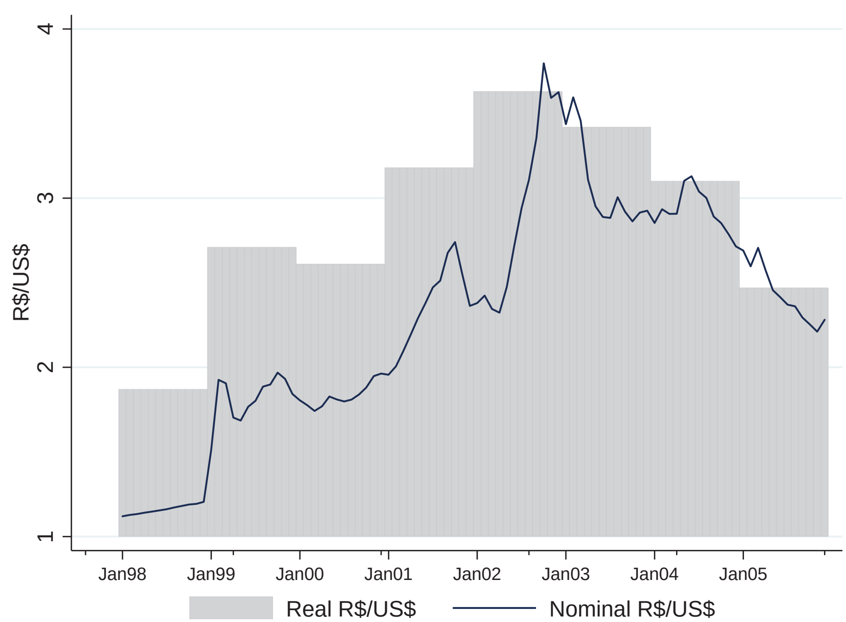
[22]However, we believe that the variable $ShDiff_s$ (the share of differentiated products measured by the *number* of products) is a better measure to infer the degree of differentiation in comparison to the *sales* of products. Estimations using the share of sales ($ShSales_s$) remain significant (results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

2005. While the size of the devaluation did not vary substantially across different bilateral currencies, it varied across industries depending on the degree of openness to trade in 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 prediction that firms innovate more following an increase in market size (an increase in $L$ in the model). Since all firms in our sample are permanent exporters, we expect them to react to the shock in a similar way.

In subsequent years, the Brazilian currency experienced further major exchange rate fluctuations which makes our empirical analysis richer. Following the main and unexpected exchange rate devaluation in 1999, the currency experienced another sharp devaluation in 2002 due to uncertainty in the Argentinean economy and uncertainty against the economic policies of presidential candidate Lula before he took office. After Lula became president and brought continuity to the former president's economic policies, the currency started to appreciate again. Besides the main shock in 1999, we may use this second large exchange rate devaluation to investigate the investment efforts of firms in subsequent years.

The monthly nominal exchange rate movements captured in Figure 4 provide a better visualization of the exchange rate evolution over the period. In the empirical analysis, we use the annual real exchange rates, which are shown in the gray bars in Figure 4.

Figure 4: Annual Real Exchange Rate and Monthly Nominal Exchange Rate for Brazil




Industry-specific exchange rates are constructed using yearly bilateral trade data from

Comtrade and NBER-UN coded by Feenstra et al. (2005) and bilateral exchange rate data from the International Monetary Fund.[23] The underlying idea of the industry-specific exchange rate shock weighted by exports is to study how the movements in different bilateral exchange rates with respect to the *real* affected different industries, depending on how much firms export to other countries. Since the mechanism we emphasize in the theory is market access, the industry-specific rates capture heterogeneous effects across industries depending on the degree of openness. The bilateral trade data is available at the 4-digit SITC level and combined with the Brazilian CNAE industry classification using publicly available concordance tables, up to 4-digit CNAE.[24] We calculate the industry-specific export-weighted exchange rates as follows:

$$XTRER_{it} = \sum_c \left( \frac{EXP_{ict}}{\sum_c EXP_{ict}} * rer_{ct} \right), \tag{37}$$

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

In the main results, we use $XTRER_{it}$ with one year lag ($XTRER_{it-1}$) and control for the firm value of imports, $\log Imports_{ft}$. In robustness checks, we also investigate the results using export and import-weighted shares, which resembles Goldberg (2004) and Almeida and Poole (2013): $TRER_{it} = \sum_c \left( \left( 0.5 \frac{EXP_{ict}}{\sum_c EXP_{ict}} + 0.5 \frac{IMP_{ict}}{\sum_c IMP_{ict}} \right) * rer_{ct} \right)$, where $\frac{IMP_{ict}}{\sum_c IMP_{ict}}$ are the import shares by industry and bilateral country pair. In both cases ($XTRER_{it}$ and $TRER_{it}$) we rescale the values to facilitate the interpretation as shares. Of course, this does not affect $\Delta XTRER_{it}$ in the empirical analysis.

Figure 5 shows the export-weighted industry-specific exchange rates for firms in sectors above and below the mean of product differentiation (high or low mean $\lambda_s$). Two important facts must be mentioned. First, Figure 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 $XTRER_{it}$ is very similar, implying that there is no clear correlation between the degree of product differentiation and the openness of the industry.[25]

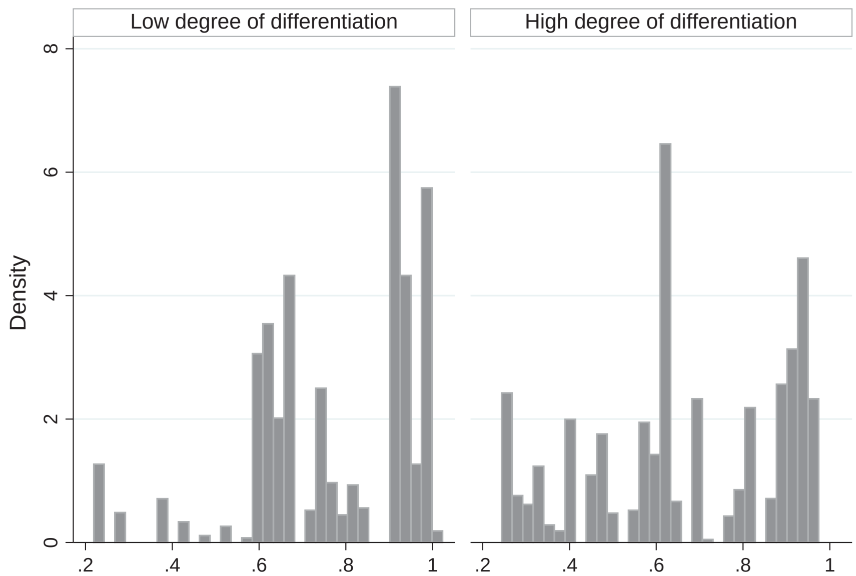
[23] The NBER-UN data coded by Feenstra et al. (2005) is based on UN Comtrade, but it is publicly available only until the year 2000. Hence, for the years 2001 until 2005 we use data downloaded directly from UN Comtrade, following the directions suggested by Feenstra et al. (2005).

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

[25] Note that for a better visualization of the figure, we show $XTRER_{it}$ in the year 1999 as a reference. Moreover, the values for $XTRER_{it}$ are rescaled as $XTRER_{it} - 1$ to allow the interpretation of the values as shares, which does not affect $\Delta XTRER_{it}$ in the empirics.

Figure A1 in the Appendix reports changes in trade-weighted exchange rates over time. The right and left panels reveal that changes in $XTRER_{it}$ are similar for both groups of industries (with high and low degree of differentiation, according to the Khandelwal (2010) classification).

Figure 5: Industry Variation in Export-weighted Real Exchange Rates for Firms in Industries with High and Low Degrees of Product Differentiation




## 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 3 shows the correlation between the innovation variables and our main variables for the degree of differentiation $(1-e)_s$: $\lambda_s$ and $ShDiff_s$. We present the correlations in terms of product and process innovation ($Product_f$ and $Process_f$) for the year 2000 as well as in terms of our alternative measures of innovation: While $Scope_f$ is related to product innovation (firms *introduce* new varieties and increase product scope), $Flexibility_f$ is related to the ability of the firm to increase the spillover effects among production lines.

We show that variables related to product innovation ($Product_f$ and $Scope_f$) are positively correlated with the degree of product differentiation. On the other hand, variables related to process innovation ($Process_f$ and $Flexibility_f$) are negatively correlated with the degree of product differentiation. Hence, results in Table 3 are consistent with the predic-

Table 3: Correlation between the Degree of Differentiation and the Outcome Variables

| $(1-e)_s$ | $Product_f$ | $Process_f$ | $Scope_f$ | $Flexibility_f$ |
|---|---|---|---|---|
| $\lambda_s$ | 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.

tions from the theoretical model. The negative correlation between $Flexibility_f$ and the degree of differentiation provides support for the assumption that spillover effects are higher in more homogeneous industries. In the section on robustness checks, we show that these correlations are not specific to the data we use. We combine innovation data for Brazilian firms from the World Bank with industry-level data. The correlations between $\lambda_s$ and the reported innovation variables confirm our results.

# 4 Empirical Strategy

Our goal in the empirical part of the paper is to test the predictions from the model regarding investment efforts of firms in industries with a different scope for product differentiation following a trade shock. We estimate the incidence of innovation investments $I_{ft}$ 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: $\lambda_s$ 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 1-year lagged export-weighted shocks, $XTRER_{i,t-1}$. An exchange rate devaluation also makes imported products more expensive. Hence, in the empirics we also control for firm total imports, $\log Imports_{ft}$. The empirical specification follows:

$$\Pr(I_{ft}=1) \;=\; F(\beta_1 XTRER_{i,t-1}+\beta_2 XTRER_{i,t-1}*(1-e)_s+(1-e)_s+\alpha_1 Z_{ft}+\nu_t+\varepsilon_{ft}), \quad (38)$$

where $f$ indexes the firm, $i$ indexes the industry, $s$ indexes the sector, and $Z_{ft}$ is a vector of firm-level time-varying control variables, as described in Table A7 in the Appendix. Initially, we include only the firm import value ($\log Imports_{ft}$) and firm size proxied by the number of workers ($\log Nworkers_{ft}$), then we subsequently add further control variables. $\varepsilon_{ft}$ is an error term and $\nu_t$ are year fixed effects.[26] $I_{ft}$ refers to the innovation conducted by a firm

[26]Note that in the theory we have used the words sector and industry interchangeably. In the empirics, $XTRER_{it}$ and $(1-e)_s$ have different levels of aggregation. Moreover, there is no clear correlation between $(1-e)_s$ and $XTRER_{it}$ or between $(1-e)_s$ and $\Delta XTRER_{it}$, as we show in Figures 5 and A1. If the correlation was high, the interaction term could capture non linearities between innovation and the independent variables.

over time, with $I_{ft} = Process_{ft}$ or $Product_{ft}$. In alternative specifications, $I_{ft} = Scope_{ft}$ or $Flexibility_{ft}$. Over the period used in the paper, firms are asked every two years about their innovation behavior during the period with exception of the year 2003, for which the time lag refers to 3 years. Hence, $t$ refers to the years of the survey.

We estimate the equation using linear probability model (LPM) in changes as well as in levels with firm fixed effects. When we estimate the equation in changes, we take two year differences to estimate the following equation:

$$\Pr(\Delta I_{ft} = 1) = F(\beta_1 \Delta XTRER_{i,t-1} + \beta_2 \Delta XTRER_{i,t-1} * (1-e)_s + \alpha_1 \Delta Z_{ft} + \Delta\nu_t + \eta_{ft}), \quad (39)$$

where $\Delta$ refers to a two year change $\Delta_{t,t-2}$, with exception of the year 2003, for which $\Delta_{t,t-3}$. After differencing equation 38, time-invariant controls such as firm-fixed effects drop out with exception of the differenced period fixed effects, $\Delta\nu_t$.[27] In the empirical analysis, it happens for few firms that the 2-digit sector classification changes over the period. We also include sector fixed effects so that we can interpret the results within a given sector.

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 investigate large exchange rate devaluations. Firms face varying degrees of exposure to foreign markets and hence varying access to foreign markets. In the Web Appendix, we provide an extension to the model where we show that the effect of a devaluation works qualitatively as an increase in market size.

We exploit the devaluation using industry-specific exchange rate shocks computed over time, $\Delta XTRER_{i,t-1}$. Following the predictions from the theoretical model, we expect $\beta_1 > 0$: An exchange rate devaluation increases the incentives for firms to innovate (because of better access to foreign markets), particularly in industries that are more open to international trade.

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 $\beta_2$, our main coefficient of interest. $\beta_2$ 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

Using the continuous measure of differentiation, $\lambda_s$, we find no statistically significant correlation between $\lambda_s$ and $\Delta XTRER_i$.

[27] We estimate the following equation: $I_{ft} - I_{f,t-2} = \beta_1(XTRER_{i,t-1} - XTRER_{i,t-3}) + \beta_2(XTRER_{i,t-1} - XTRER_{i,t-3}) * (1-e)_s + \alpha_1(Z_{ft} - Z_{ft-2}) + \nu_t - \nu_{t-2} + \eta_{ft}$.

effects from innovation are higher, leading to firms investing more in process innovation. Hence, $\beta_2 > 0$ in case the dependent variable is $\Delta Product_{ft}$ (firms in sectors with a high degree of product differentiation invest more in product innovation), and $\beta_2 < 0$ when the dependent variable is $\Delta Process_{ft}$ (firms in more differentiated sectors invest less in process innovation in comparison to firms in more homogeneous sectors).

# 5 Results

Table 4 presents the main empirical results from our paper. The results hold using LPM in changes and in levels adding firm fixed effects. We perform several robustness checks in the next section. The errors are clustered at the sector-year level.

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) and (3) in Table 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 ($\Delta XTRER_{it-1} > 0$), firms have higher incentives to invest in product and process innovation.

Table 4: Effect of $\Delta XTRER_{it-1}$ on Product and Process Innovation

| *Dependent variable:* | $\Delta Process_{ft}$ | | $\Delta Product_{ft}$ | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| $\Delta XTRER_{it-1}$ | 0.198*** | 0.338*** | 0.216*** | 0.153** |
| | (0.00432) | (0.0566) | (0.00453) | (0.0665) |
| $\lambda_s * \Delta XTRER_{it-1}$ | | -0.0786** | | 0.0741** |
| | | (0.0320) | | (0.0333) |
| Constant | yes | yes | yes | yes |
| $\Delta \log Imports_{ft}$ | yes | yes | yes | yes |
| $\Delta \log Nworkers_{ft}$ | yes | yes | yes | yes |
| Sector fixed effects | yes | yes | yes | yes |
| Period fixed effects | yes | yes | yes | yes |
| Observations | 6,054 | 6,054 | 6,054 | 6,054 |
| R-squared | 0.418 | 0.419 | 0.445 | 0.445 |

However, the main interest of the paper refers to the differential effects across sectors and industries. The differential effects using our main measure of differentiation $\lambda_s$ are shown in columns (2) and (4) of Table 4. The results confirm the main predictions from our theoretical model. Following an exchange rate devaluation ($\Delta XTRER_{it-1} > 0$), firms in industries with a high degree of product differentiation invest more in product innovation relative to other firms ($\beta_2 > 0$ when $\Delta I_{ft} = \Delta Product_{ft}$) whereas firms in industries with a low degree of product differentiation invest more in process innovation relative to other firms ($\beta_2 < 0$ when $\Delta I_{ft} = \Delta Process_{ft}$).[28]

One may argue that the measures of product and process innovation used in Table 4 are disconnected from the theoretical model. Changes in process innovation ($\Delta Process_{ft}$) may reflect an innovation not directly related to the internalization of spillovers. We address this concern using an alternative measure of innovation related to spillover effects, $\Delta Flexibility_{ft}$. Results presented in Table 5 reveal that estimations are robust to this alternative measure of process innovation.[29]

A similar concern refers to the mechanism related to product innovation ($\Delta Product_{ft}$). 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, $\Delta Scope_{ft}$. Results shown in Table 5 are consistent with the baseline estimations from Table 4.

Table 5: Effect of $\Delta XTRER_{it-1}$ on Product Scope and Production Flexibility

| *Dependent variable:* | $\Delta Flexibility_{ft}$ | | $\Delta Scope_{ft}$ | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| $\Delta XTRER_{it-1}$ | 0.194*** | 0.380*** | 0.196*** | 0.167** |
| | (0.00490) | (0.0611) | (0.00528) | (0.0663) |
| $\lambda_s * \Delta XTRER_{it-1}$ | | -0.105*** | | 0.0367*** |
| | | (0.0345) | | (0.00685) |
| Constant | yes | yes | yes | yes |
| $\Delta \log Imports_{ft}$ | yes | yes | yes | yes |
| $\Delta \log Nworkers_{ft}$ | yes | yes | yes | yes |
| Sector fixed effects | yes | yes | yes | yes |
| Period fixed effects | yes | yes | yes | yes |
| Observations | 4,851 | 4,851 | 6,054 | 6,054 |
| R-squared | 0.425 | 0.426 | 0.430 | 0.431 |

[28]If we evaluate firms at the 10th percentile of $\lambda_s$, a 10 percentage point depreciation increases the incentives for product innovation by roughly 2 percent whereas in more differentiated industries (90th percentile of $\lambda_s$) this increase is 3.5 percent. For process innovation, firms in the 10th percentile (more homogeneous) increase process innovation by 1% more relative to firms in the 90th percentile (more differentiated). In terms of standard deviations, if we take a firm at the mean $\lambda_s$ as a reference point a devaluation with the magnitude of the year 1999 increases the incentives for product innovation by 0.8% more for firms one standard deviation above the mean $\lambda_s$ and decreases the incentives for process innovation for these firms by 0.6% with respect to firms at the mean $\lambda_s$. Importantly, for the whole distribution of firms in our sample, the incentives for both process and product innovation are non-negative.

[29]Note that not all firms answer the question concerning flexibility, which implies that the sample is much smaller. Although we cannot compare the magnitudes of the coefficients in Tables 4 and 5, we can show that the results are consistent.

# 6 Robustness Checks

**Rauch (1999) Measure of Product Differentiation** We use $ShDiff_s$ as an alternative measure to $\lambda_s$ and replicate the interaction effects from Table 4. The results are shown in Table A1 columns (2) and (4). While smaller in magnitude in the case of product innovation, the results confirm the expected coefficients for $\beta_1$ and $\beta_2$.[30]

**Degree of Differentiation: Firm-level Measure** As a further alternative measure to $\lambda_s$, we build a firm-level ladder $\lambda_f$ 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. We combine these data and create the mean ladder at the firm level $\lambda_f$ 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 $t-2$. $\lambda_f$ provides higher variation in comparison to $\lambda_s$: While $\lambda_s$ for 1998 has a standard deviation of 0.21, $\lambda_f$ has a standard deviation of 0.6. The means are very close, 1.73 for $\lambda_s$ and 1.75 for $\lambda_f$.

The results using $\lambda_f$ are shown in Table A1 in columns (1) and (3) 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.[31] Thus, 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 perform both types of innovation. Many firms invest simultaneously in product and process innovation following exchange rate shocks. 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 $\Delta I_{ft} = \Delta Process_{ft}$ or $\Delta Product_{ft}$ consider all firms that reported process and product innovation efforts, respectively, here we evaluate the effect for firms that reported only one *or* the other innovation type. $\Delta Process\_only_{ft} = 1$ for firms that reported only process innovation, zero otherwise. Similar for product innovation ($\Delta Product\_only_{ft}$). Estimations with $\Delta Process\_only_{ft}$ and $\Delta Product\_only_{ft}$ as dependent

[30] The results remain robust if we regroup the reference priced goods in the group of differentiated goods, as $ShDiff_{s(n+r)} = \frac{Nproducts_{s,(n+r)}}{Nproducts_{s,(w+r+n)}}$.

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

variables reveal that the results are in general larger in magnitudes for firms reporting only one type of innovation (results in columns (5) to (6) from Table A1). 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 and without Firm Size** We add several firm-level variables to the main specification. Firms that are larger, pay higher wages, and export to larger and more competitive markets are in general more innovative. Hence, we investigate the stability of our results when adding the following firm characteristics: Average wages of workers ($\log Wages_{ft}$), the number of products exported by the firm ($\log Nproducts_{ft}$), and the average size of the destination country of exports (proxied by the destination GDP) weighted by firm sales ($\log DestSize_{ft}$). The coefficients shown in Table A3 reveal that the results remain stable, which suggests that omitted variables bias is not a major concern. The summary statistics and variable description are reported in Tables A6 and A7.

In the baseline regressions, we control for firm size in particular because of proposition 2, which is conditional on firm size. However, this variable might capture the heterogeneity of innovation responses across firms. Hence, we also report results without firm size, which is proxied by the number of employees. The results shown in columns (1) and (5) in Table A3 reveal that the results remain stable and robust.

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

*First*, we look at 2-year lagged exports. One concern with the estimations using $\Delta XTRER_{it-1}$ is endogeneity between trade and the exchange rate. We avoid this concern using 2-year lagged export shares ($\frac{EXP_{ic,t-2}}{\sum_c EXP_{ic,t-2}}$) along with exchange rates in $t-1$. Columns (1) and (3) in Table A2 show that results remain robust when we use 2-year lagged trade shares.

*Second*, instead of using industry-specific export-weighted rates controlling for firm imports we use $TRER_{it-1}$, which refers to industry-specific rates weighted by imports and exports as standard in the literature, as follows:

$TRER_{it} = \sum_c \left( \left( 0.5\frac{EXP_{ict}}{\sum_c EXP_{ict}} + 0.5\frac{IMP_{ict}}{\sum_c IMP_{ict}} \right) * rer_{ct} \right)$. Although this specification is closer to the literature it might also reflect factors unrelated to market access, which is the main mechanism in our framework. However, the results are also robust to the use of this alternative measure as shown in Table A2 columns (2) and (4).

**Exchange Rate Shock: Results using RER** Because exchange rates affect innovation through market access, the export weights provide an important source of variation across industries as firms in more open industries show a greater reaction to the exchange rate devaluation. However, we also show that our results are not driven by these weights. In the results reported in columns (3) and (6) in Table A4, we provide evidence that the exchange rate devaluation, measured by $\Delta RER_{t-1}$ (RER with one year lag) had a direct and positive effect on the innovation behavior of firms.

**Probit Model** The linear probability model used in the baseline results has the advantage of being easy to estimate and to interpret the coefficients. Though unbiased, it poses important disadvantages. To deal with the concerns of the linear estimation, we conduct robustness checks using a probit model. The results are reported in Table A4.

In results available upon request and in an earlier version of the paper (Flach and Irlacher, 2015), we also conduct robustness checks using seemingly unrelated regressions to allow the error terms across equations to be correlated using the equations with $\Delta Process_{ft}$ or $\Delta Product_{ft}$ as dependent variables. Also in this case, the results remain stable and significant.

**Falsification Exercise** As a falsification exercise for our results, we exploit data for the period 2003-2005. We use the exchange rate shock in 1999 and estimate the effect on the innovation behavior of firms in the period 2003-2005 using firm fixed effects. In results shown in Table A4 columns (2) and (4) we show that in this case the coefficients are not significant, as expected.

**Results Using Innovation Data from the World Bank** One could argue that the correlation we find between $\lambda_s$ 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 does not allow us to fully test our model. However, we can calculate the correlation between $\lambda_s$ and innovation ($Product\_WB_f$ and $Process\_WB_f$) and compare with the correlations we find using the PINTEC data. Results shown in Table A5 confirm the correlations presented in Table 3 using the PINTEC firm-level data.

# 7 Conclusion

This paper 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 paper, we provide a new model of MPFs, allowing for endogenous investments in both product and process innovation. Following an increase in market size, we show how firms increase investments of both types. The focus of this model 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. For firms in homogeneous industries, the mechanism works in an opposite fashion.

Our model provides novel predictions that are tested using Brazilian firm-level data. We combine detailed information on the two types of innovation featured in our theory with large exchange rate devaluations 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. 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 focus more on process innovation.

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# A Appendix

## A.1 Derivation of Eq. (32)

Combining Eqs. (20) at $i = \delta$ and (25) yields:

$$b' r_k (1-e)\, y(\delta)^2 = \left((1-\theta(e))\, y(\delta) + \theta(e) Y\right)\left((1-\theta(e))\, y(\delta) - \theta(e) Y\right) + r_\delta r_k. \quad (40)$$

The expression on the right-hand side $\left((1-\theta(e))\, y(\delta) + \theta(e) Y\right)\left((1-\theta(e))\, y(\delta) - \theta(e) Y\right)$ can be rewritten as: $\left((1-\theta(e))\, y(\delta)\right)^2 - \left(\theta(e) Y\right)^2$. Solving for $y(\delta)$ yields the expression in Eq. (32).

## A.2 Market Size Effect - Proposition 1

We totally differentiate the two equilibrium conditions for scale and scope in Eqs. (29) and (33) and write the results in matrix notation.

$$\begin{bmatrix} r_k \delta \left(a - c - c_1 \frac{\delta}{2}\right) & -2\left(\left(b' r_k (1-e) - (1-e^\kappa)^2\right) y(\delta) + \delta e^{2\kappa} Y\right)\delta \\ 2\left(\left(e b' r_k - e^\kappa \left(2(1-e^\kappa) + e^\kappa \delta\right)\right) - \frac{e^{2\kappa} Y}{y(\delta)}\right) Y & \left(r_k c_1 - 2 e^{2\kappa} Y\right)\delta \end{bmatrix}$$

$$\times \begin{bmatrix} d\ln Y \\ d\ln\delta \end{bmatrix} = -\begin{bmatrix} 2Y(1-e+e\delta) \\ \left((1-e)\, y(\delta) + 2eY\right) \end{bmatrix} b' r_k d\ln b' + \begin{bmatrix} \delta \\ 1 \end{bmatrix} r_k a\, d\ln a \quad (41)$$

To derive this matrix, we use information from Eqs. (29), (31), and (32). The determinant $\Delta$ of the system is always positive. The fact that $\Delta > 0$ ensures a unique and stable equilibrium. Condition 1 stated in Eq. (24) ensures that $\left(\left(e b' r_k - e^\kappa \left(2(1-e^\kappa) + e^\kappa \delta\right)\right) - \frac{e^{2\kappa} Y}{y(\delta)}\right) > 0$. To proof the latter result, we compute an alternative expression for total firm scale by integrating over per variety scale in Eq. (26):

$$Y = \frac{c_1 \left(\frac{\delta^2}{2}\right)}{2\left(b'(1-e) - \frac{(1-e^\kappa)^2}{r_k}\right)} + \delta y(\delta). \quad (42)$$

Combining the latter expression with the condition in Eq. (24) yields:

$$e b' r_k y(\delta) > 2 e^\kappa (1-e^\kappa)\, y(\delta) + e^{2\kappa} \delta y(\delta) + e^{2\kappa} Y + e^{2\kappa} \frac{c_1 \left(\frac{\delta^2}{2}\right)}{2\left(b'(1-e) - \frac{(1-e^\kappa)^2}{r_k}\right)}, \quad (43)$$

and ensures that $\Delta > 0$.

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

$$\frac{d\ln Y}{d\ln b'} = \frac{1}{\Delta}\begin{vmatrix} -2Y(1-e+e\delta)b'r_k & -2\left(\left(b'r_k(1-e)-(1-e^{\kappa})^2\right)y(\delta)+\delta e^{2\kappa}Y\right)\delta \\ -\left((1-e)\,y(\delta)+2eY\right)b'r_k & \left(r_k c_1 - 2e^{2\kappa}Y\right)\delta \end{vmatrix} < 0. \tag{44}$$

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

$$\frac{d\ln Y}{d\ln a} = \frac{1}{\Delta}\begin{vmatrix} \delta a r_k & -2\left(\left(b'r_k(1-e)-(1-e^{\kappa})^2\right)y(\delta)+\delta e^{2\kappa}Y\right)\delta \\ a r_k & \left(r_k c_1 - 2e^{2\kappa}Y\right)\delta \end{vmatrix} > 0. \tag{45}$$

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

$$\frac{d\ln \delta}{d\ln b'} = \frac{1}{\Delta}\begin{vmatrix} r_k\delta\left(a-c-c_1\frac{\delta}{2}\right) & -2Y(1-e+e\delta)b'r_k \\ 2\left(\left(eb'r_k - e^{\kappa}\left(2\left(1-e^{\kappa}\right)+e^{\kappa}\delta\right)\right)-\frac{e^{2\kappa}Y}{y(\delta)}\right)Y & -\left((1-e)\,y(\delta)+2eY\right)b'r_k \end{vmatrix} < 0. \tag{46}$$

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

$$\Delta_{b'} = -\left\{\begin{matrix} \left(b'r_k(1-e+e\delta)-(1-e^{\kappa}+e^{\kappa}\delta)^2\right)\left((1-e)\,y(\delta)\right) \\ +2Y\left(\left(2e^{\kappa}\left(1-e^{\kappa}\right)-e\left(1-e^{2\kappa}\right)+\left(1-e\right)e^{2\kappa}\delta\right)+\left(1-e+e\delta\right)\frac{e^{2\kappa}Y}{y(\delta)}\right) \end{matrix}\right\} < 0. \tag{47}$$

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 $a$:

$$\frac{d\ln \delta}{d\ln a} = \frac{1}{\Delta}\begin{vmatrix} r_k\delta\left(a-c-c_1\frac{\delta}{2}\right) & \delta a r_k \\ 2\left(\left(eb'r_k - e^{\kappa}\left(2\left(1-e^{\kappa}\right)+e^{\kappa}\delta\right)\right)-\frac{e^{2\kappa}Y}{y(\delta)}\right)Y & a r_k \end{vmatrix} > 0. \tag{48}$$

The sign of the matrix $\Delta_a$ is clearly positive as:

$$\Delta_a = \left(b'r_k(1-e)-1+e^{\kappa}\left(2-e^{\kappa}\right)+\frac{e^{2\kappa}\delta Y}{y(\delta)}\right)2Yar_k > 0. \tag{49}$$

**Effect on Process Innovation $K$:** After having determined the market size effects on scale $Y$ and scope $\delta$, identifying the market size effect on process innovation $K$ is trivial. Totally differentiating Eq. (30) yields the following results:

$$r_k K\frac{d\ln K}{d\ln b'} = \left(1-e^{\kappa}+e^{\kappa}\delta\right)Y\frac{d\ln Y}{d\ln b'} + e^{\kappa}\delta Y\frac{d\ln \delta}{d\ln b'} < 0, \tag{50}$$

and

$$r_k K \frac{d \ln K}{d \ln a} = (1 - e^{\kappa} + e^{\kappa}\delta) Y \frac{d \ln Y}{d \ln a} + e^{\kappa}\delta Y \frac{d \ln \delta}{d \ln a} > 0. \tag{51}$$

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.

## A.3 Effect of Degree of Product Differentiation - Proposition 2

Differentiating Eq. (33) with respect to $e$ and substituting information from Eq. (32), gives:

$$\frac{\partial \ln \delta}{\partial \ln e} = -\frac{((2Y - y(\delta))(eb' r_k - 2\kappa e^{\kappa}(1 - e^{\kappa}))\, y(\delta) - 2\kappa e^{2\kappa} Y (2(\delta - 1)\, y(\delta) + Y))}{(c_1 r_k - 2e^{2\kappa} Y)\, y(\delta)\, \delta}. \tag{52}$$

For very strong (weak) spillovers, i.e. low (high) values of $\kappa$ 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. (52) depends on the perceived costs of process innovation $b' r_k$ (see discussion of Condition 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. (33) with respect to $e$ and evaluate it at $e = 0$:

$$\frac{\partial \delta}{\partial e} \Big|_{e=0} = -\frac{b'(2Y - y(\delta))}{c_1} < 0. \tag{53}$$

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

## A.4 Robustness Checks

Table A1: Effect of $\Delta XTRER_{it-1}$ on Innovation Using Alternative Measures of Differentiation

| *Dependent variable:* | $\Delta Process_{ft}$ | | $\Delta Product_{ft}$ | | Only process | Only product |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| $\Delta XTRER_{it-1}$ | 0.346*** | 0.321*** | 0.183*** | 0.0983*** | 0.348*** | 0.147*** |
| | (0.0824) | (0.0566) | (0.0331) | (0.0362) | (0.0568) | (0.0326) |
| $\lambda_f * \Delta XTRER_{it-1}$ | -0.0832* | | 0.0603*** | | | |
| | (0.0477) | | (0.0193) | | | |
| $ShDiff_s * \Delta XTRER_{it-1}$ | | -0.156** | | 0.0732** | | |
| | | (0.0784) | | (0.0332) | | |
| $\lambda_s * \Delta XTRER_{it-1}$ | | | | | -0.0839*** | 0.0959*** |
| | | | | | (0.0321) | (0.0360) |
| Constant | yes | yes | yes | yes | yes | yes |
| $\Delta \log Imports_{ft}$ | yes | yes | yes | yes | yes | yes |
| $\Delta \log Nworkers_{ft}$ | yes | yes | yes | yes | yes | yes |
| Sector FE | yes | yes | yes | yes | yes | yes |
| Period FE | yes | yes | yes | yes | yes | yes |
| Observations | 6,054 | 6,054 | 6,054 | 6,054 | 6,054 | 6,054 |
| R-squared | 0.423 | 0.424 | 0.415 | 0.448 | 0.422 | 0.443 |

Table A2: Effect on Innovation Using Alternative Measures of Trade-Weighted Exchange Rates

| *Dependent variable:* | $\Delta Process_{ft}$ | | $\Delta Product_{ft}$ | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| $\Delta XTRER_{it-2}$ | 0.318*** | | 0.152** | |
| | (0.0567) | | (0.0660) | |
| $\lambda_s * \Delta XTRER_{it-2}$ | -0.0684** | | 0.0710** | |
| | (0.0320) | | (0.0331) | |
| $\Delta TRER_{it-1}$ | | 0.347*** | | 0.184*** |
| | | (0.0568) | | (0.0664) |
| $\lambda_s * \Delta TRER_{it-1}$ | | -0.0836*** | | 0.0798** |
| | | (0.0320) | | (0.0363) |
| Constant | yes | yes | yes | yes |
| $\Delta \log Imports_{ft}$ | yes | no | yes | no |
| $\Delta \log Nworkers_{ft}$ | no | yes | no | yes |
| Sector FE | yes | yes | yes | yes |
| Period FE | yes | yes | yes | yes |
| Observations | 6,054 | 6,054 | 6,054 | 6,054 |
| R-squared | 0.425 | 0.423 | 0.442 | 0.465 |

Table A3: Effect of $\Delta XTRER_{it-1}$ - Results Adding further Control Variables

| *Dependent variable:* | $\Delta Process_{ft}$ (1) | (2) | (3) | (4) | $\Delta Product_{ft}$ (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| $\Delta XTRER_{it-1}$ | 0.341*** | 0.333*** | 0.342*** | 0.260*** | 0.146** | 0.155** | 0.156** | 0.158** |
| | (0.0566) | (0.0565) | (0.0565) | (0.0562) | (0.0664) | (0.0665) | (0.0665) | (0.0666) |
| $\lambda_s * \Delta XTRER_{it-1}$ | -0.0805** | -0.0763** | -0.0824*** | -0.0571* | 0.0979*** | 0.0713** | 0.0733** | 0.0705** |
| | (0.0320) | (0.0319) | (0.0319) | (0.0315) | (0.0297) | (0.0334) | (0.0333) | (0.0335) |
| $\Delta \log Nproducts_{ft}$ | | 0.0959*** | | | | 0.0988*** | | |
| | | (0.0363) | | | | (0.0361) | | |
| $\Delta \log DestSize_{ft}$ | | | 0.0397 | | | | 0.0199** | |
| | | | (0.0360) | | | | (0.00886) | |
| $\Delta \log Wages_{ft}$ | | | | 0.0979*** | | | | 0.0766 |
| | | | | (0.0297) | | | | (0.0799) |
| Constant | yes | yes | yes | yes | yes | yes | yes | yes |
| $\Delta \log Imports_{ft}$ | yes | yes | yes | yes | yes | yes | yes | yes |
| $\Delta \log Nworkers_{ft}$ | no | yes | yes | yes | no | yes | yes | yes |
| Sector FE | yes | yes | yes | yes | yes | yes | yes | yes |
| Period FE | yes | yes | yes | yes | yes | yes | yes | yes |
| Observations | 6,054 | 6,054 | 6,054 | 6,041 | 6,054 | 6,054 | 6,054 | 6,041 |
| R-squared | 0.420 | 0.421 | 0.422 | 0.442 | 0.447 | 0.446 | 0.446 | 0.451 |

Table A4: Further Robustness Checks

| *Dependent variable:* | $\Delta Process_{ft}$ Probit (1) | 2003-2005 (2) | RER (3) | $\Delta Product_{ft}$ Probit (4) | 2003-2005 (5) | RER (6) |
|---|---|---|---|---|---|---|
| $\Delta XTRER_{it-1}$ | 2.900*** | | | 0.620*** | | |
| | (0.348) | | | (0.224) | | |
| $\lambda_s * \Delta XTRER_{it-1}$ | -1.148*** | | | 0.523*** | | |
| | (0.186) | | | (0.135) | | |
| $\Delta XTRER_{i,1997-1999}$ | | 0.221 | | | 0.104 | |
| | | (0.262) | | | (0.170) | |
| $\lambda_s * \Delta XTRER_{i,1997-1999}$ | | -0.0454 | | | 0.0140 | |
| | | (0.171) | | | (0.0154) | |
| $\Delta RER_{t-1}$ | | | 0.0413** | | | 0.0389** |
| | | | (0.0162) | | | (0.0162) |
| Constant | yes | yes | yes | yes | yes | yes |
| Sector FE | yes | yes | yes | yes | yes | yes |
| $\Delta \log Imports_{ft}$ | yes | yes | yes | yes | yes | yes |
| $\Delta \log Nworkers_{ft}$ | yes | yes | yes | yes | yes | yes |
| Observations | 6,053 | 2,080 | 6,054 | 6,054 | 2,080 | 6,054 |

Table A5: Correlation between $\lambda_s$ and Innovation Using World Bank Data for Brazil

| $(1-e)_s$ | $Process\_WB_f$ | $Product\_WB_f$ |
|---|---|---|
| $\lambda_s$ | -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.

## A.5 Data Appendix

PINTEC Surveys: The surveys are conducted by the Statistical Office in Brazil and follow the Oslo Manual from OECD, which refers to the international guidelines for collecting and interpreting innovation data. The information is strictly confidential and can be used solely for statistical purposes. The researcher does not see firm names and can only report summary statistics/results if confidentiality is guaranteed (for instance, it is not allowed to report summary statistics in case the set of firms is too small). Firms cannot suffer any type of legal process or retaliation in response to the information provided in the survey. Moreover, firms are obliged by law number 5,534 to report information to the Statistical Office. This reduces concerns with non-response, which is a recurring problem in surveys.

The survey is conducted in the following fashion. First, the Statistical Office identifies a contact person in the enterprise, preferably the individual responsible for the innovation activities or a manager. Second, an employee of the Statistical Office conducts (1) a face-to-face interview in the large firms (with more than 500 employees) in case they are located in the main Brazilian states,[32] or (2) a telephone interview assisted by computer (CATI – Computer Assisted Telephone Interview) in the case of the other enterprises. The main reason is because many firms, particularly those smaller in size, might not be familiar with the concepts of innovation asked in the questionnaire whereas the Statistical Office employee is familiar with these concepts.[33] Hence, the setup of the survey reduces concerns with reporting mistakes and with non-reporting.

Table A6: Summary Statistics

| **Variable** | **Mean** | **Std. Dev.** | **N** |
|---|---|---|---|
| $ShDiff_s$ | 0.727 | 0.122 | 2080 |
| $\lambda_s$ | 1.745 | 0.183 | 2080 |
| $FDI_{ft}$ | 0.192 | 0.394 | 2080 |
| $\log Ndestinations_{ft}$ | 1.523 | 1.028 | 2080 |
| $\log Wages_{ft}$ | 8.282 | 0.638 | 2078 |
| $\log Nworkers_{ft}$ | 5.497 | 1.173 | 2080 |
| $\log Imports_{ft}$ | 13.356 | 2.614 | 2080 |
| $\Delta XTRER_{it-1}$ | 0.167 | 0.196 | 2080 |

[32] Amazonas, Pará, Ceará, Pernambuco, Alagoas, Bahia, Minas Gerais, Espírito Santo, Rio de Janeiro, Sao Paulo, Paraná, Santa Catarina, Rio Grande do Sul, and Goias.

[33] During the interview, the employee explains the meaning of product and process innovation. In the Methodology Appendix, several examples of product and process innovation are provided for every industry. For instance, in the textile industry product innovation means the introduction of a new eco-friendly product line or production with synthetic instead of animal fiber. The introduction of new colors for the same product does not classify as product innovation. For process innovation, buying new machines does not classify as process innovation but introducing a new computerized drawing software (for instance, CAD/CAM) classifies as process innovation.

Table A7: Description of the Dependent Variable and Main Explanatory Variables

| Variable | Variable description | Data source |
|---|---|---|
| **Innovation variables** | | |
| $\Delta Process_{ft}$ | $Process_{ft} = 1$ if<br>the firm reported process innovation, zero otherwise<br>(information available for the period 1998-2005)<br>(questions v10 and v11 from the surveys) | PINTEC |
| $\Delta Product_{ft}$ | $Product_{tf} = 1$ if<br>the firm reported product innovation, zero otherwise<br>(information available for the period 1998-2005)<br>(questions v07 and v08 from the surveys) | PINTEC |
| $\Delta Scope_{ft}$ | $Scope_{ft} = 1$ if<br>Innovation was important/very important to increase product scope<br>(question v78=1 or v78=2)[1] and zero if innovation was not important<br>to increase product scope (v78=3) or if the firm did not innovate (v78=4) | PINTEC |
| $\Delta Flexibility_{ft}$ | $Flexibility_{ft} = 1$ if<br>Innovation was important/very important to increase product flexibility<br>(question v83=1 or v83=2)[1] and zero if innovation was not important<br>to increase flexility (v83=3) or if the firm did not innovate (v83=4) | PINTEC |
| **Exchange rates:** | | |
| $XTRER_{it}$ | Export-weighted industry-specific exchange rates<br>$\sum_c \left( \frac{X_t^{ic}}{\sum_c X_t^{ic}} rer_t^c \right)$ | COMTRADE,<br>NBER and IMF |
| **Degree of product differentiation:** | | |
| $\lambda_s$ | Degree of product differentiation based on Khandelwal (2010),<br>$\lambda_s$ is the average by sector $s$ , defined according to the IBGE classification. | Khandelwal (2010) |
| $\lambda_f$ | Degree of product differentiation based on Khandelwal (2010),<br>$\lambda_f = \frac{\sum_{fp} \lambda_{fp}}{N}$, where $p$ is a HS 6-digit product exported by the firm. | Khandelwal (2010) |
| $ShDiff_s$ | Share of differentiated products in $s$, following Rauch (1999) | Rauch (1999) |
| **Firm initial characteristics:** | | |
| $FDI_{ft}$ | Foreign ownership dummy | PINTEC |
| $Nworkers_{ft}$ | Number of workers in $f$ (measure of firm size) | RAIS-Brazil |
| $Imports_{ft}$ | fob import value | SECEX |
| $Wages_{ft}$ | Average wages of workers | RAIS-Brazil |
| $Ndestinations_{ft}$ | Number of export destinations | SECEX |
| $Nproducts_{ft}$ | Number of products exported | SECEX |

Notes: Firms are surveyed with an interval of 2 or 3 years. One example of a survey is available at:
`http://www.pintec.ibge.gov.br/downloads/PUBLICACAO/Publicacao%20PINTEC%202000.pdf`

**1.** The questions for scope and flexibility are 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).

Figure A1: $\Delta XRER_{t-1}$ for Industries with Different Degrees of Product Differentiation