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Abstract

We investigate the effect 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. We test these predictions using Brazilian firm-level data. Following an exchange rate devaluation, firms have better access to foreign markets and exploit economies of scale in innovation. We evaluate the differential effects across industries and show that the type of innovation depends on the degree of product differentiation.

JEL-Code: F120, F140, L250.

Keywords: multi-product firms, innovation, product differentiation, cannibalization effect, spillovers, market size effect.

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1 Introduction

Successful manufacturing firms continuously innovate to maintain their position in the market and to attend consumers' demand. Recent contributions in the international trade literature emphasize the importance of intra-firm adjustments through innovation in explaining welfare gains from trade liberalization, besides the well-established intra-industry gains from entry and exit of firms. This literature highlights innovation as a new dimension into 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 new products of entering firms but, first and foremost, from product innovation by incumbent firms.[3] Therefore, understanding innovation strategies and within-firm adjustments of multi-product firms (MPFs) is crucial for the analysis of aggregate productivity and variety gains.

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

The contribution of 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 engage more 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 for Spanish firms that investments in R&D are the primary source of productivity growth. Within sectors, between 65 percent and 90 percent of productivity growth arises through intra-firm productivity enhancing activities.

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

present in an MPF setting. Firms may decide to expand their product range or to lower production costs, and the net effect in terms of returns to innovation is a priori unclear.

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

Our theoretical model builds on Eckel and Neary (2010) and Eckel et al. (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.[4] However, our theory introduces several novel features. *First*, we explicitly allow for two types of R&D. Therefore, we assign fixed costs to additional products to model the decision on optimal scope, which is closer to the notion of product innovation.[5] *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, close to their core competence. *Third*, another novel feature of our framework is to allow for spillover effects between the production processes within the firm. We relate the strength of these cost linkages to the degree of product differentiation in a sector. This occurs because products that are closer substitutes tend to have more similar production processes (in comparison to highly differentiated products).

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

[4] 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).

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

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

The predictions from the model are tested using detailed firm-level data, which has two distinctive features. *First*, we can exploit detailed information on innovation investments by firms, mainly over the years 1998-2000. *Second*, the event of a major and unexpected exchange rate devaluation in January 1999 provides 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 of the industry.

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

Our paper is closely related to the literature on MPFs in international trade that features a cannibalization effect.[6] Our theory builds on Eckel et al. (2015), who incorporate an endogenous investment in product quality in the framework by Eckel and Neary (2010). We abstract from investments in quality and instead focus on investments in product and process innovation. The paper that is closest in spirit to ours is Dhingra (2013), who also

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

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

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

2 The Model

Our theory draws on a simple model of MPFs that choose their optimal spending on product and process innovation. Both types of innovation are costly and, therefore, firms weight the returns to innovation against the costs. The returns to innovation are in the focus of this 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 innovating new products. These innovation patterns follow from demand and cost linkages, both related to the degree of product differentiation in a sector. Since these linkages determine the returns to innovation, we will introduce them at the very outset.

We begin with a detailed analysis of consumer behavior and the underlying preference structure in section 2.1. In this part, we show how the demand linkages enter our framework and relate them to the degree of product differentiation in a sector. In section 2.2, we present the firm side of the model. We start with the production cost function, which is characterized by flexible manufacturing. Moreover, firms can undertake investments in process innovation to reduce production costs of a product, which may generate spillovers between production lines. We refer to this feature as a cost linkage and argue that its strength decreases in the degree of product differentiation. Firms consider both linkages when maximizing their profits. Finally, section 2.3 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 Ω of goods out of 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:[7]

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

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 per variety consumption and $Q \equiv \int_{i\in\widetilde{\Omega}} q(i)di$ stands for total consumption of the representative consumer. The parameter e plays a very important role in our model and describes the degree of product differentiation. We assume that e lies strictly between zero and one and define the parameter as an inverse measure for product differentiation. This means that lower values of e imply more differentiated and hence less substitutable prod-

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

ucts. Throughout the analysis, we will distinguish industries along the degree of product differentiation. We simply refer to a *homogeneous* industry as an industry with a relatively high value of e. Accordingly, a *differentiated* industry means an industry with a value of e close to zero. A detailed discussion of the role of the parameter e in our model will follow later on in the analysis.

Consumers maximize utility subject to the budget constraint $q_0 + \int_{i\in\widetilde{\Omega}} p(i)q(i)di = I$. Hence, individual income I is spent on consumption of the outside good and the potential basket $\widetilde{\Omega}$ of the differentiated good. $p(i)$ is the price of variety i and the numeraire good is sold at a price $p_0 = 1$. We assume that consumers demand a positive amount of the outside good $q_0 > 0$ to ensure consumption of the differentiated good. Maximizing utility and aggregating individual demand functions yields a linear market demand:[8]

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

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

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

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

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

In addition to the cross elasticities, we also compute the price elasticity of demand to relate e to our empirical measure of differentiation. The empirical part of the paper uses the Khandelwal (2010) classification as the preferred measure for product differentiation. This

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

measure is created by evaluating changes in prices conditional on market shares: A product is classified as more differentiated if the firm can increase prices without losing market shares. To connect this to our theoretical model, we compute the price elasticity of demand and show how it responds to a change in the degree of differentiation in a sector. Given the linear demand system in Eq. (3), there exists an upper bound of the price, where demand $x(i)$ is just driven to zero:

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

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

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

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 ε_i increases when products become more homogeneous.

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

This implies that the parameter e in our theoretical model is closely related to the Khandelwal (2010) measure of differentiation which we use in the empirical part of our 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.[9] 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 an exchange rate devaluation for incumbent firms. Moreover, the exchange rate devaluation leads to better access to foreign markets without increasing competition. Hence, our way of writing the theory is motivated by deriving predictions that can directly be addressed in the empirical analysis.

We construct a theoretical model in which MPFs optimally choose between two types

[9] The model could be extended to the oligopoly case. See the Appendix in Eckel et al. (2015).

of investment. Firstly, firms invest in new product lines and thereby extend their product portfolio. Secondly, firms may decide for each of their products how much to invest in the production technology. Both types of investment depend on the degree of product differentiation through the demand and cost linkages taken into account by a firm. In the previous section, we have already introduced the demand linkages into our model. We argue that the demand linkages in particular determine the returns to product innovation. While deciding on the optimal number of products, the firm considers the negative impact of the marginal good on the demand for the rest of its products. Hence, the more similar are the products within the portfolio, the stronger will be the cannibalization effect of the marginal variety. Consequently, we show that the optimal product range will be smaller in a 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, therefore, on the degree of product differentiation. Thus, firms in homogeneous sectors will invest more in process innovation as they can internalize more spillovers between production lines.

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

Firms can reduce production costs through variety specific process innovation. Furthermore, we allow for investment spillovers between products. To reduce production costs of variety i, a firm undertakes process innovation $k(i)$ which reduces production costs at a diminishing rate. The variety specific costs savings from innovation are given by $2k(i)^{0.5}$. As mentioned earlier, part of the process optimization of one variety is applicable to all other varieties, which implies that production of variety i benefits from all investments undertaken on all the other products $K_{-i} \equiv \int_{\Omega \backslash i} k(i)^{0.5}\, di$. 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 better 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 on in the analysis.

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

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

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

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

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

Optimal Scale Maximizing profits in Eq. (11) with respect to scale $x(i)$ implies the following first-order condition:[10]

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

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

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

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

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

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

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

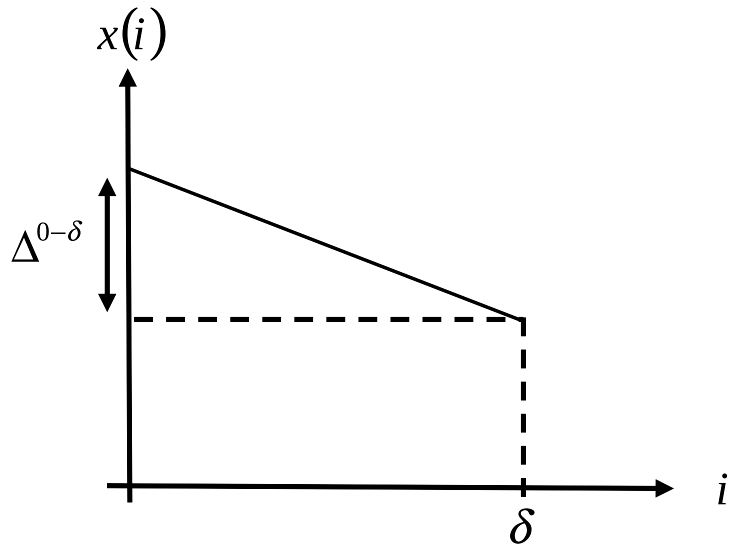
$$\frac{\partial x(i)}{\partial X} = -\frac{e}{1-e} < 0, \tag{15}$$

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

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

As a result of the underlying cost structure with flexible manufacturing, optimal scale of the core product is the largest, and output per variety diminishes with distance to the core product. We illustrate the output scheme in Figure 1, where $\Delta^{0-\delta}$ indicates the difference in scale between the core and marginal product in the portfolio. The exact mathematical expression for $\Delta^{0-\delta}$ is determined later on in the analysis.

Figure 1: Output Schedule



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

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

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:

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

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

$$\frac{\partial \pi}{\partial k(i)} = \left(1-\theta\left(e\right)\right)k\left(i\right)^{-0.5}x\left(i\right) + \theta\left(e\right)k\left(i\right)^{-0.5}X - r_k = 0. \tag{19}$$

Solving for optimal investments in variety i yields:[11]

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

Eq. (20) shows that optimal investment reflects economies of scale through both per variety output $x\left(i\right)$ and total firm output X. Given that the output of the core variety is the highest, a firm will put most effort in optimizing the production process of this variety.[12] However, the first-order condition in Eq. (20) implies that the larger the spillovers $\theta\left(e\right)$ on other products within the firm, the more equally a firm spreads investments across products. In the extreme case of $\theta\left(e\right) = 1$, 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 gives total firm investment in process innovation

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

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

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

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

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

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 on all other products (cannibalization) and the positive externality (spillovers in process innovation).[13]

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

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 which 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:*

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

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

[13] The second-order condition is given by: $\frac{\partial^2 \pi}{\partial \delta^2} = \left[-c_1 - 2\left(b' ex(\delta) - 2\theta(e)\, k(\delta)^{0.5}\right)\right] x(\delta) < 0$. To see that this condition is negative as required, consider Condition 1.

In the following, we express a firm's optimal scope in terms of scale of the marginal product $x(\delta)$. To do so, we substitute the output of the marginal variety from Eq. (13) and its respective price-cost margin from Eq. (18) into the first-order condition for scope (22):

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

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

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

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

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 δ, 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 δ. The larger is the distance to the core product, the lower will be the efficiency of the marginal product. The latter effect is magnified for higher values of c_1, as this variable determines how much marginal costs increase with rising distance to the core product. Moreover, $\Delta^{0-\delta}$ decreases in the strength of the spillovers $\theta(e)$. As stated in Lemma 1, firms concentrate their investment in process R&D on the core varieties. However, if spillover effects are large, the marginal varieties benefit more from the investments in the high-scale core varieties.

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

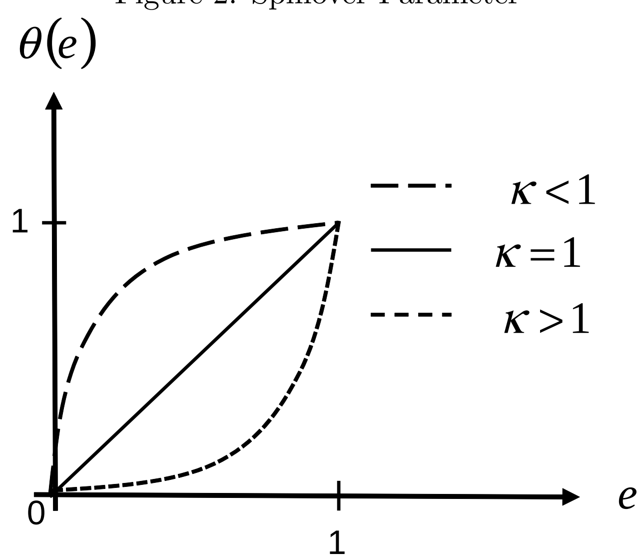
2.3 Comparative Statics

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

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

Figure 2 illustrates this functional form and the role of κ in determining the strength of spillovers. Since $e \in [0, 1]$, lower values of κ translate into a stronger spillover effect. In the

Figure 2: Spillover Parameter



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 κ grow large decreases the importance of spillovers within the firm.

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

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

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

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

The parameter κ 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 κ, i.e. $\frac{\partial K}{\partial \kappa} < 0$. Furthermore, process innovation K reflects economies of scale as it depends on total firm scale X. Using information from Eqs. (20), (29), and (30) together with Eq. (13), we can express optimal scale per variety as:

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

Within our framework, we have two opposing effects of total scale X on per variety output. On the one hand, rising total output induces the firm to invest more in process innovation, which increases per variety output. On the other hand, rising total scale intensifies cannibalization within the portfolio. The latter effect reduces per variety output. However, Condition 1 stated in Eq. (24) guarantees that the spillover effect cannot dominate the cannibalization effect, i.e. $\frac{\partial x(i)}{\partial X} < 0$.

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

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

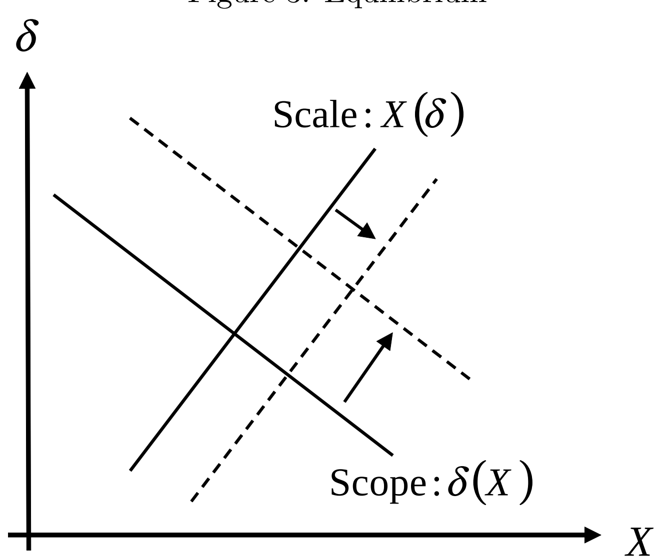
The formal derivation of this expression is presented in the Appendix. Eq. (32) implicitly defines product scope δ in terms of the output of the marginal variety. Solving for δ gives the explicit expression for product scope:

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

Eqs. (32) and (33) reveal that higher costs for product innovation r_δ decrease the optimal product range. The latter implies a higher output of the marginal variety δ (see Eq. (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_δ. This structure translates an increase in the market size L into lower perceived costs of product innovation for the firm.

Inspecting the previous equations indicates that the equilibrium in our model can be characterized in terms of two endogenous variables: δ and X. In Figure 3, Eq. (29) is labeled by "Scale: $X(\delta)$" and describes a positive relationship between total firm output X and scope δ. Through adding additional products, an MPF can increase its total output. Eq. (33) establishes a negative relationship between X and δ. The downward-sloping curve "Scope: $\delta(X)$" illustrates that rising firm output intensifies the cannibalization effect of the marginal variety. Therefore, an MPF reduces its product scope when its total output increases. In the intersection of both curves in Figure 3, the two equilibrium conditions for

Figure 3: Equilibrium



scale and scope are satisfied.[14] Once we have determined the equilibrium values of δ and X, we compute the equilibrium value of process innovation K. In the next step, we derive the main testable predictions from the model.

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

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

An increase in the market size L reduces the slope b' of the demand function in Eq. (3). In the Appendix, we derive the total derivatives of the equilibrium conditions in terms of scale X (Eq. (29)) and scope δ (Eq. (33)), which lead to the following results.

We show that increases in the market size lead to higher total firm output X. Three different intra-firm adjustments lead to this result. The first adjustment comes from the increased demand in the larger market. The second and third adjustments come from the impact of product and process innovation on total firm scale X. We show that despite cannibalization is intensified through the larger X, a firm will invest in new products in a larger market. In Figure 3, both curves "Scale: $X(\delta)$" and "Scope: $\delta(X)$" are shifted to the right, though "Scope: $\delta(X)$" shifts more. The cannibalization effect of increasing firm scale X on scope δ can be visualized by comparing the product range before and after the shift of "Scale: $X(\delta)$". Technically the increase in product scope is caused by the fact that in Eq. (33) the costs for product innovation r_δ enter multiplied by the parameter b'. As explained earlier in the text, a larger market size reduces the perceived innovation costs for the firm. Finally, we analyze the impact of the market size on process innovation K. As discussed earlier, process innovation is subject to economies of scale as in a larger market innovation costs can be spread over more units. From inspection of Eq. (30), we see that the rise in δ and X causes more spending in process innovation. Captured by the term $\frac{(1-e^{\kappa}+e^{\kappa}\delta)^2}{r_k}$ in Eq. (29), the process innovation effect contributes to the rise in firm scale X. We summarize the market size effect on optimal firm behavior in the following proposition and test these results in the empirical part of the paper.

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

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

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

Sectors with Different Scope for Product Differentiation We derive a second testable prediction of our model with respect to the degree of product differentiation in a sector. A simple comparison between brick production and the automotive sector makes it clear that there is a lot more scope for differentiation in the latter sector. We argue that the degree of differentiation is crucial in explaining the innovation behavior of firms. Recall, that degree of differentiation determines the strength of the two linkages within our framework. A low degree of differentiation (high e) causes high cannibalization and high spillover effects and, therefore, promotes process innovation. One can think again of our example of an MPF producing bricks that are slightly differentiated. It is plausible to assume that a large fraction of the investment in the production line of one specific brick is applicable to the production of all other bricks produced by the same firm. However, introducing one further brick will have a strong cannibalizing impact on the initial portfolio. Differentiating Eq. (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 (more homogeneous) bricks. The more differentiated two cars are, the lower will be the number of identical parts used in production and, therefore, the lower will be the spillovers in production. However, for a firm producing multiple cars, the negative externality of adding an additional car declines the higher is the degree of differentiation (i.e. the lower is the cannibalization effect). Again, we hold firm size fixed and differentiate Eq. (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 δ. On the one hand, the marginal product cannibalizes, on the other hand, all initial products benefit from process-spillovers from the marginal product. Differentiating Eq. (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.

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

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. For the main results, we use data for the period 1998-2000. In robustness checks and a falsification exercise, we extend the analysis for the years 2000-2005. 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 survey from PINTEC (Brazilian Firm Industrial Innovation Survey). We combine firm-level data with industry-level data to investigate how different industries react to a trade shock in terms of their investments in innovation.

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

3.1 Innovation Variables

The innovation survey provides detailed information on innovation investments of 3,070 manufacturing exporters for which we can exploit time-varying information.[15] 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 $Product_f = 1$ if a firm f in industry i reported important efforts to do product innovation (zero otherwise), and $Process_f = 1$ if the firm reported process innovation (zero otherwise).

Product innovation does not necessarily mean an *increase* in product scope (suggested by our theory), since firms could simultaneously add and drop varieties or change the attributes of existent varieties. Therefore, in order to get closer to our theoretical mechanism, we use a further question from the survey related to product scope: 3. Importance of the innovation to increase product scope, $Scope_f$. This categorical variable (with four degrees of importance) relates innovation to increases in product scope. We transform this variable in a dummy $Scope_f = 1$ if the firm reports that it was important or very important to increase scope (and zero otherwise).

For process innovation, the variable $Process_f$ may also not be directly related to the mechanism we propose in the theory (that some firms internalize spillover effects and, therefore, invest more in process innovation). Thus, to evaluate the importance of spillover effects, we use information related to increases in the flexibility of the production process. In particular, we use the following question from the survey: 4. Importance of the innovation to increase production flexibility, $Flexibility_f$. $Flexibility_f$ is a categorical variable (with four degrees of importance) related to the ability of the firm to make the production process more flexible and increase the spillover effects among production lines. Therefore, it is consistent with the mechanism of the theoretical model, predicting that firms may internalize intra-firm spillover effects. The description of variables is found in Table 14 in the Appendix.

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

Table 1 presents summary statistics for the baseline indicators of innovation in 2000, following the exchange rate shock.[16] About half of the firms reported changes in process and

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

[16] Values are based on a sample of 3,070 firms (sample used in the paper).

42 percent changes in product.[17] The interest of the study is to provide more information on the innovation choices of firms in different industries.

Table 1: Percentage of Firms by Innovation Status in the Year 2000

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

3.2 Degree of Product Differentiation

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

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

[17] 42 percent of firms conducted product innovation and 14 percent reported *only* product innovation (no process innovation). 48 percent of firms conducted process innovation and 20 percent *only* process innovation. 28 percent of the firms reported both product and process innovation.

Rauch (1999) Classification of Goods Rauch (1999) classifies trade data into three groups of commodities: **w**, homogeneous (organized exchange) goods, which are goods traded in an organized exchange; **r**, reference priced goods, not traded in an organized exchange, but which have some quoted reference price, such as industry publications; and **n**, differentiated goods, without any quoted price. Using this classification at the 4-digit SITC product classification (issued by the United Nations), we create a measure of the share of products from a firm classified as differentiated goods: $ShDiff_s = \frac{Nproducts_{s,n}}{Nproducts_{s,(w+r+n)}}$, where $ShDiff_s$ is the share of products produced by sector s classified as differentiated goods. Also in this case, we map the Rauch (1999) classification of goods to the 2-digit industry classification of differentiation from IBGE. Moreover, as an alternative measure, we estimate $ShSales_s = \frac{Sales_n}{TotalSales_{(w+r+n)}}$, where $ShSales_s$ is the share of sales of differentiated products in comparison to total sales in a sector s.[18]

We use λ_s as our benchmark measure, since λ_s provides higher variation in comparison to $ShDiff_s$. While λ_s is created from a continuous variable (*product ladder*), the Rauch (1999) classification is created from a binary variable (products classified as differentiated or non-differentiated goods). Thus, $ShDiff_s$ may be inaccurate and subject to measurement error. We keep the Rauch (1999) classification for robustness checks. Summary statistics for both measures of differentiation are shown in Table 2.

Table 2: Degree of Product Differentiation by Industry

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

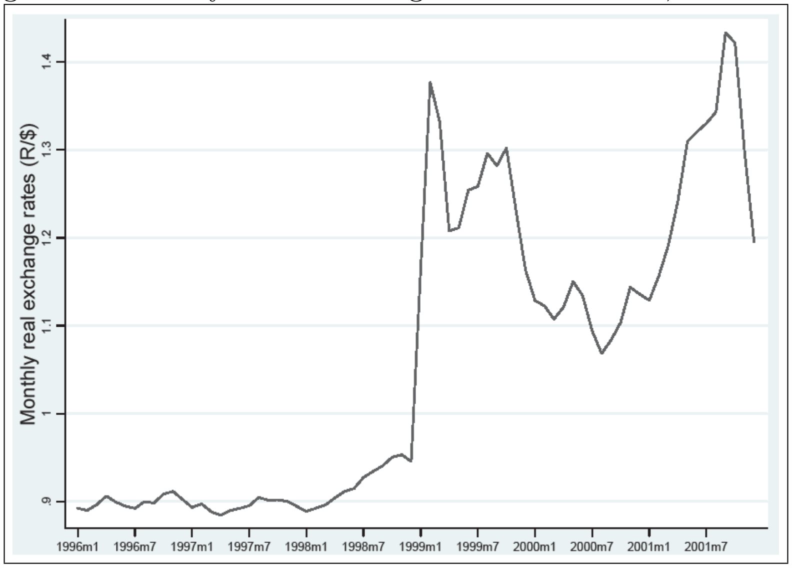
3.3 Industry-specific Exchange Rates

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 the exchange rate in this period. While the size of the devaluation did not vary across different bilateral currencies, it varied across industries depending on the degree of openness to trade of the industry. We exploit the variation across time in exchange rates for industries with different degrees of exposure to global markets using trade-weighted industry-specific exchange rate shocks. In this way, we can empirically test the theoretical prediction that firms innovate more following an increase in market size

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

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

Figure 4: Monthly Real Exchange Rates for Brazil, 1996-2001



Industry-specific exchange rates are constructed using yearly bilateral trade data from NBER-UN coded by Feenstra et al. (2005) and bilateral exchange rate data from the International Monetary Fund. The underlying idea of the industry-specific exchange rate shock is to study how the movements in different bilateral exchange rates with respect to the *real* affected different industries, depending on how much they trade with other countries. The bilateral trade data from NBER-UN provides information on bilateral trade flows at the 4-digit SITC level. The SITC classification is combined with the Brazilian CNAE industry classification using publicly available concordance tables up to 4-digit CNAE.[19] Following Goldberg (2004) and Almeida and Poole (2013), we calculate the industry-specific exchange rates as follows:

$$TRER_{it} = \sum_{c} \left(\left(0.5 \frac{X_{ict}}{\sum_c X_{ict}} + 0.5 \frac{M_{ict}}{\sum_c M_{ict}} \right) * rer_{ct} \right), \tag{37}$$

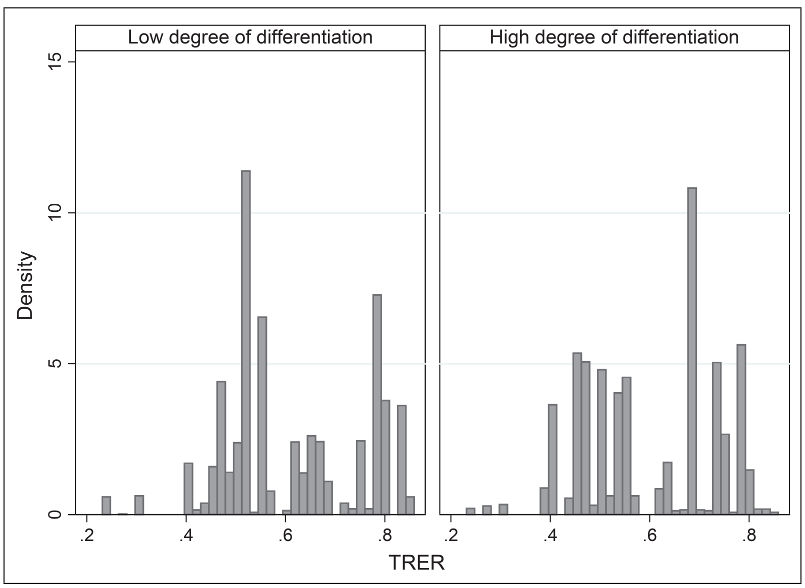
where i is industry, c is country, and t is time, such that the bilateral real exchange rate rer_{ct}, measured by the Brazilian currency *real* with respect to the trading partner c, is weighted by the industry-specific trade shares. The industry-specific shares are time-varying import shares ($\frac{M_{ict}}{\sum_c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

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

Figure 5 shows the trade-weighted industry-specific exchange rates for firms above and below the mean of product differentiation (high or low mean λ_s). Two important facts must be mentioned. First, Figure 5 illustrates a substantial heterogeneity across industries in the trade-weighted exchange rates. Second, the figure shows that in both groups of firms/industries the distribution of $TRER_{it}$ is very similar, implying that there is no clear correlation between the degree of product differentiation and the openness of the industry.

Figure 6 in the Appendix reports changes in trade-weighted exchange rates over time. The right and left panels reveal that changes in $TRER_{it}$ are similar for both groups of industries (with high and low degree of differentiation, according to the Khandelwal (2010) classification).

Figure 5: Industry Variation in Trade-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 $(1-e)_s$: λ_s and $ShDiff_s$. We present the correlations in terms of product and process innovation ($Product_f$ and $Process_f$) 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.

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

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

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

We show that variables related to product innovation ($Product_f$ 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. Therefore, results in Table 3 are consistent with the predictions from the theoretical model. Moreover, 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 λ_s and innovation ($Product_f$ and $Process_f$) 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 different scope for product differentiation, following a trade shock. We estimate the incidence of changes in innovation investments ΔI_f as a function of the degree of differentiation $(1-e)_s$ in the sector s in which the firm operates. To investigate the degree of differentiation $(1-e)_s$, we use two different measures: λ_s according to Khandelwal (2010) and $ShDiff_s$ following Rauch (1999), as described in the data section. We are interested in the differential effects for industries with different degrees of trade openness, measured by changes in time-varying trade-weighted shocks, $\Delta TRER_i$, using 2-year differences. In the main results, we use the period 1998-2000 (exchange rates before and after the devaluation in January 1999), and later on we use information for the period 2000-2005. The empirical specification follows:

$$\Pr(\Delta I_f = 1) \ = \ F(\beta_1 \Delta TRER_i + \beta_2 \Delta TRER_i * (1-e)_s + \alpha_1 \Delta X_f + \upsilon_s + \varepsilon_f), \qquad (38)$$

where f indexes the firm, i indexes the industry, s indexes the sector, and ΔX_f is a vector of firm-level time-varying control variables, as described in Table 14 in the Appendix. Initially, we include only changes in firm size, then subsequently we add further control variables. For simplicity, we omit time subscripts for Δ, which refer to a 2-year lag. ε_f is an error term. υ_s are sector fixed effects, such that we can interpret results within industries in a given sector.[20] ΔI_f refers to innovation changes conducted by the firm over the period, with $\Delta I_f = \Delta Process_f$ or $\Delta Product_f$. In alternative specifications, $\Delta I_f = \Delta Scope_f$ or $\Delta Flexibility_f$.

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

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

Concerning the functional form of equation (37), we estimate our empirical model using probit and linear probability models.[21] We also conduct robustness checks using seemingly unrelated regressions - SUR, to allow the error terms across equations to be correlated

[20] Note that in the theory we have used the words sector and industry interchangeably. In the empirics it is important that $TRER_i$ and $(1-e)_s$ have different levels of aggregation, such that the interaction term provides the relevant variation. Therefore, the fact that both variables come from different classification of goods/industries and are aggregated at different levels is an advantage of our approach. Moreover, there is no clear correlation between $(1-e)_s$ and $TRER_i$ or between $(1-e)_s$ and $\Delta TRER_i$, as we show in Figures 5 and 6. If the correlation was high, the interaction term could capture non linearities between innovation and the independent variables. Using the continuous measure of differentiation, λ_s , we find no statistically significant correlation between λ_s and $\Delta TRER_i$.

[21] The linear probability model has the advantage of being easy to estimate and to interpret the coefficients. However, though unbiased, it poses important disadvantages. To deal with the concerns with the linear estimation, we estimate a probit model.

(equations with $\Delta Process_f$ or $\Delta Product_f$ as dependent variable).

5 Results

Tables 4 and 5 present the main empirical results from our paper. In Table 4, we first investigate whether changes in market size lead to more innovation. As predicted by the theoretical model, when the market size grows (L increases) incentives to innovate increase for all firms and all types of innovation ($\beta_1 > 0$). Columns (1) to (4) in Table 4 confirm that $\beta_1 > 0$ for product and process innovation, meaning an increase in the predicted probability of innovation: Following an industry-specific exchange rate devaluation ($\Delta TRER_i > 0$), firms have higher incentives to invest in product and process innovation. Results are statistically significant using LPM and Probit, shown in the odds and even columns, respectively. Unless otherwise stated, results reported for Probit in the tables include the marginal effects, their standard errors, and the value of the likelihood function. Marginal effects are computed at means of all variables (means are reported in Tables 2 and 13). At mean values, the average marginal effect is around 0.273 for product and 0.305 for process innovation, with a p-value of 0.001 in both cases, meaning that the effect is significant.

Table 4: Effect of $\Delta TRER_i$ on Innovation

Dependent variable:	$\Delta Process_f$		$\Delta Product_f$	
	Probit	LPM	Probit	LPM
	(1)	(2)	(3)	(4)
$\Delta TRER_i$	0.305***	0.296***	0.273***	0.259***
	(0.0872)	(0.0819)	(0.0846)	(0.0778)
Constant	yes	yes	yes	yes
$\Delta logNworkers_f$	yes	yes	yes	yes
Sector s fixed effects	yes	yes	yes	yes
Log-pseudolikelihood	-1895.239		-1776.380	
Pseudo R-squared	0.010		0.039	
R-squared		0.104		0.146
Observations	3,070	3,070	3,070	3,070

However, the main interest of the paper refers to the differential effects across sectors and industries. The differential effects using our main measure of differentiation λ_s are shown in Table 5. Results confirm the main predictions from our theoretical model. Following an exchange rate devaluation ($\Delta TRER_i > 0$), firms in industries with a high degree of product differentiation invest more in product innovation relative to other firms ($\beta_2 > 0$ when $\Delta I_f = \Delta Product_f$), while firms in industries with a low degree of product differentiation invest more in process innovation relative to other firms ($\beta_2 < 0$ when $\Delta I_f = \Delta Process_f$).

Results hold for both estimation strategies (Probit and LPM).

Table 5: Effect of $\Delta TRER_i$ on Innovation for Firms in Different Industries

Dependent variable:	$\Delta Process_f$		$\Delta Product_f$	
	Probit	LPM	Probit	LPM
	(1)	(2)	(3)	(4)
$\lambda_s * \Delta TRER_i$	-0.125***	-0.124***	0.107***	0.106***
	(0.033)	(0.0331)	(0.0155)	(0.0154)
$\Delta TRER_i$	0.344***	0.329***	0.213**	0.199**
	(0.0882)	(0.0810)	(0.0837)	(0.0773)
Constant	yes	yes	yes	yes
$\Delta logNworkers_f$	yes	yes	yes	yes
Sector s fixed effects	yes	yes	yes	yes
Log-pseudolikelihood	-1892.544		-1775.112	
Pseudo R-squared	0.011		0.040	
R-squared		0.104		0.147
Observations	3,070	3,070	3,070	3,070

For probit, we compute the difference in probabilities depending on different values of $\Delta TRER_i$ and λ_s, since the value of the interaction effect changes upon the value of the continuous predictor variable. At mean values of all variables, the marginal effect of $\Delta TRER_i$ is 0.213 for product and 0.344 for process innovation, as reported in Table 5. For the interaction term, the marginal effect is 0.107 for product and -0.125 for process innovation, evaluated at mean values. Crucially, the interaction effect is statistically significant and has the expected sign for all observations in the sample, including minimum and maximum values.[22] Thus, our results confirm that firms in more homogeneous sectors are significantly more likely to do process innovation following the shock, whereas firms in more differentiated sectors are more likely to do product innovation. Columns (2) and (4) report results for the LPM. If we evaluate mean values of $\Delta TRER_i$ and λ_s, a decrease in λ_s by two standard deviations leads to an increase in the probability to do process innovation by roughly 2 percent, with this value being higher for firms in sectors with higher initial λ_s. For product innovation, an increase in λ_s by two standard deviations leads to an increase in product innovation by roughly 4 percent.

One may argue that the measures of product and process innovation used in Table 5 are disconnected from the theoretical model. Changes in process innovation ($\Delta Process_f$) may reflect an innovation not directly related to internalization of spillovers. We address this concern using an alternative measure of innovation related to spillover effects, $\Delta Flexibility_f$.

[22] The interaction effect is computed conditional on the independent variables. The analysis of cross derivatives and cross differences shows that the interaction effect varies for different values of the observations, but has the expected sign: It is positive for product and negative for process innovation.

Results presented in Table 6 reveal that estimations are robust to this alternative measure of process innovation.

A similar concern refers to the mechanism related to product innovation ($\Delta Product_f$). Investments in product innovation may reflect changes in an already existent product rather than the creation of an additional variety. We address this concern using an alternative measure of innovation related to changes in product scope, $\Delta Scope_f$. Results shown in Table 6 are consistent with the baseline estimations from Table 5.

Table 6: Effect of $\Delta TRER_i$ on Product Scope and Production Flexibility

Dependent variable:	$\Delta Scope_f$		$\Delta Flexibility_f$	
	Probit	LPM	Probit	LPM
	(1)	(2)	(3)	(4)
$\lambda_s * \Delta TRER_i$	0.060***	0.0497***	-0.0615***	-0.0614***
	(0.0199)	(0.0123)	(0.0195)	(0.0196)
$\Delta TRER_i$	0.381***	0.303***	0.279**	0.272**
	(0.0889)	(0.0548)	(0.1171)	(0.114)
Constant	yes	yes	yes	yes
$\Delta logNworkers_f$	yes	yes	yes	yes
Sector s fixed effects	yes	yes	yes	yes
Log-pseudolikelihood	-567.767		-1255.563	
Pseudo R-squared	0.050		0.019	
R-squared		0.094		0.069
Observations	3,070	3,070	1,971	1,971

6 Robustness Checks

Rauch (1999) Measure of Product Differentiation We use $ShDiff_s$ as an alternative measure to λ_s and replicate the interaction effects from Table 5. Results are shown in Table 7 columns (1) and (3). While smaller in magnitudes, the effect confirms the expected coefficients for β_1 and β_2.

Degree of Differentiation: Firm-level Measure As a further alternative measure to λ_s, we build a firm-level ladder λ_f starting from the 10-digit product classification, made available by Khandelwal (2010). This measure allows us to exploit the degree of differentiation at the firm-level, since we have information on all 6-digit products exported by Brazilian firms. Thus, we combine these data and create the mean ladder at the firm level λ_f corresponding to the average *ladder* of the products exported by the firm, as follows: $\lambda_f = \frac{\sum_{fp} \lambda_{fp}}{N}$, where N is the initial number of products exported by the firm in the year 1998. λ_f provides higher variation in comparison to λ_s: While λ_s has a standard deviation of 0.21, λ_f has a standard deviation of 0.6. The means are very close, 1.73 for λ_s and 1.75 for λ_f.

Results using λ_f are shown in Table 7 in columns (2) and (4) and are consistent with our predictions. However, data at the firm and product-level on the degree of differentiation are not essential to our argument and may be subject to endogeneity once we exploit time variation.[23] Therefore, our preferred empirical specification uses information at the sector and industry-level.

Asymmetries across Firms One important concern with our baseline estimations refers to firms that do both types of innovation. Many firms invest simultaneously in product and process innovation following the exchange rate shock. Therefore, we evaluate asymmetries across different groups of firms. In particular, we evaluate the effects for firms that do only one type of innovation.

While the baseline estimations using $\Delta I_f = \Delta Process_f$ or $\Delta Product_f$ consider all firms that reported process and product innovation efforts, respectively, here we evaluate the effect for firms that reported only one *or* the other type of innovation. $\Delta Process\_only_f = 1$ for firms that reported only process innovation, zero otherwise. Similar for product innovation ($\Delta Product\_only_f$). Estimations with $\Delta Process\_only_f$ and $\Delta Product\_only_f$ as dependent variables reveal that results are in general larger in magnitudes for firms reporting only one type of innovation (results in columns (1) to (4) from Table 8). We interpret this result as follows: Firms in the extremes of the distribution of product differentiation have lower incentives to invest in both types of innovation. Imagine firms producing bricks versus firms producing luxury watches (a highly homogeneous and a highly differentiated product, respectively). While firms in the middle of the distribution will have higher incentives to allocate part of their resources to each type of innovation, firms in the extremes of the distribution such as watches and bricks have higher returns to innovation when they allocate resources in only one type of innovation.

Results Adding further Firm-level Control Variables We add several firm-level variables to the main specification and show that results remain stable. The stability of results suggest that omitted variables might not be a major concern.

The variables we add relate to firm initial characteristics in year 1998, $X_{f,t=0}$. Firms that are larger, foreign-owned and with a more skilled labor force are in general more innovative. Therefore, we investigate the stability of our results when adding the following firm initial

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

conditions: Number of workers as a proxy for firm size ($\log Nworkers_{f,t=0}$), foreign ownership dummy ($FDI_{f,t=0}$), share of workers with tertiary education as a proxy for worker skills ($Skills_{f,t=0}$), the number of products exported by the firm ($\log Nproducts_{f,t=0}$), and the number of destinations of exports ($\log Ndestinations_{f,t=0}$). The description of variables and the associated means and standard deviations are reported in Table 13.

Results are shown in Table 9. As expected, all coefficients are positive and statistically significant, meaning that larger, foreign-owned, and firms with a higher share of skilled workers do more innovation. Crucially, as shown in Table 9, the interaction term shown by β_2 remains significant and stable through all specifications. In results available upon request, we also add the change in these same variables over the period. While the point estimates are in many cases not statistically significant (since the period is relatively short), the signs are informative and consistent with the literature.

Results Using SUR We check whether our results remain robust to further estimations strategies. In the baseline results, we have estimated LPM and Probit separately for product and process innovation. To allow the error terms of the two equations to be correlated, we estimate a seemingly unrelated regressions model (SUR). Results reported in Table 11 reveal that coefficients are the same in comparison to the LPM (as expected), but the error terms are slightly higher when we allow them to be correlated. Results remain significant in all cases.

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

First, we look at lagged exports. One concern with the estimations using $\Delta TRER_i$ is endogeneity between trade and the exchange rate. We avoid this concern using lagged import shares ($\frac{M_{ic,t-1}}{\sum_c M_{ic,t-1}}$) and lagged export shares ($\frac{X_{ic,t-1}}{\sum_c X_{ic,t-1}}$). Columns (1) and (2) in Table 10 show that results remain robust when we use lagged exports.

Second, instead of using industry-specific import shares ($\frac{M_{ict}}{\sum_c M_{ict}}$) and export shares ($\frac{X_{ict}}{\sum_c X_{ict}}$) to construct $TRER_{it}$, we construct an alternative measure using only export shares, as follows: $XTRER_{it} = \sum_c \left(\frac{X_{ict}}{\sum_c X_{ict}} * rer_{ct} \right)$. The advantage of using export shares separately is to separate export shocks from import shocks. One concern with the estimations using $\Delta TRER_i$ is that an exchange rate shock may mean increases in market size for some industries but not for others (depending on input intensity, among others). Using the exchange rate shock separately for imports and exports, we exploit whether factors unrelated to market size are driving our results. Results are reported in Table 10 in columns (3) and

(4). Also in this case our main hypotheses remain robust.

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

The World Bank data do not allow us to fully test our model. However, we can calculate the correlation between λ_s and innovation ($Product\_WB_f$ and $Process\_WB_f$) and compare with the correlations we find using the PINTEC (2000) data. Results shown in Table 12 confirm the correlations presented in Table 3 using the PINTEC (2000) firm-level data.

Results Using a Longer Panel and a Falsification Exercise One could argue that it takes time for firms to react to an exchange rate shock in terms of their innovation behavior. To overcome this issue, we exploit data for a longer period (until 2003). In results available upon request, we show that results remain significant, though the magnitudes are much smaller. Most likely, using a longer time period leads to other confounding factors.

Moreover, as a falsification exercise, we exploit data for the period 2003-2005. We investigate the same exchange rate shock and estimate the effect on innovation using the surveys for the years 2003 and 2005. In this case, results are not significant, as expected.

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 the market size, we show how firms increase investments of both types. The focus of this model, however, is on an industry-specific trade-off between the two types of innovation, which arises through demand and cost linkages specific to MPFs. Both linkages are related to the degree of product differentiation in a sector, leading to heterogenous returns to the two types of innovation across industries.

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

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

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8 Appendix

8.1 Derivation of Eq. (32)

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

$$b' r_k (1 - e) x(\delta)^2 = ((1 - \theta(e)) x(\delta) + \theta(e) X)((1 - \theta(e)) x(\delta) - \theta(e) X) + r_\delta r_k. \quad (39)$$

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

8.2 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.

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

$$= - \begin{bmatrix} 2X(1 - e + e\delta) \\ ((1-e) x(\delta) + 2eX) \end{bmatrix} b' r_k d\ln b' + \begin{bmatrix} \delta \\ 1 \end{bmatrix} r_k a d\ln a \quad (40)$$

To derive this matrix, we use information from Eqs. (29), (31), and (32). The determinant Δ 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 $\left((e b' r_k - e^{\kappa}(2(1 - e^{\kappa}) + e^{\kappa}\delta)) - \frac{e^{2\kappa} X}{x(\delta)}\right) > 0$. To proof the latter result, we compute an alternative expression for total firm scale by integrating over per variety scale in Eq. (26):

$$X = \frac{c_1 \left(\frac{\delta^2}{2}\right)}{2\left(b'(1-e) - \frac{(1-e^{\kappa})^2}{r_k}\right)} + \delta x(\delta). \quad (41)$$

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

$$e b' r_k x(\delta) > 2e^{\kappa}(1 - e^{\kappa}) x(\delta) + e^{2\kappa}\delta x(\delta) + e^{2\kappa} X + e^{2\kappa} \frac{c_1 \left(\frac{\delta^2}{2}\right)}{2\left(b'(1-e) - \frac{(1-e^{\kappa})^2}{r_k}\right)}, \quad (42)$$

and ensures that $\Delta > 0$.

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

$$\frac{d\ln X}{d\ln b'} = \frac{1}{\Delta}\begin{vmatrix} -2X(1-e+e\delta)b'r_k & -2\left(b'r_k(1-e)-(1-e^{\kappa})^2\right)x(\delta)\delta \\ -\left((1-e)x(\delta)+2eX\right)b'r_k & \left(r_kc_1-2e^{2\kappa}X\right)\delta \end{vmatrix} < 0. \quad (43)$$

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

$$\frac{d\ln X}{d\ln a} = \frac{1}{\Delta}\begin{vmatrix} \delta a r_k & -2\left(b'r_k(1-e)-(1-e^{\kappa})^2\right)x(\delta)\delta \\ a r_k & \left(r_kc_1-2e^{2\kappa}X\right)\delta \end{vmatrix} > 0. \quad (44)$$

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

$$\frac{d\ln \delta}{d\ln b'} = \frac{1}{\Delta}\begin{vmatrix} r_k\delta\left(a-c-c_1\frac{\delta}{2}\right) & -2X(1-e+e\delta)b'r_k \\ \left(\left(eb'r_k-e^{\kappa}\left(2\left(1-e^{\kappa}\right)+e^{\kappa}\delta\right)\right)-\frac{e^{2\kappa}X}{x(\delta)}\right)2X & -\left((1-e)x(\delta)+2eX\right)b'r_k \end{vmatrix} < 0. \quad (45)$$

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

$$\Delta_{b'} = -\left\{\begin{array}{c} \left(b'r_k(1-e+e\delta)-(1-e^{\kappa}+e^{\kappa}\delta)^2\right)\left((1-e)x(\delta)\right) \\ +2X\left(\left(2e^{\kappa}\left(1-e^{\kappa}\right)-e\left(1-e^{2\kappa}\right)+(1-e)e^{2\kappa}\delta\right)+(1-e+e\delta)\frac{e^{2\kappa}X}{x(\delta)}\right) \end{array}\right\} < 0. \quad (46)$$

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

$$\frac{d\ln \delta}{d\ln a} = \frac{1}{\Delta}\begin{vmatrix} r_k\delta\left(a-c-c_1\frac{\delta}{2}\right) & \delta a r_k \\ \left(\left(eb'r_k-e^{\kappa}\left(2\left(1-e^{\kappa}\right)+e^{\kappa}\delta\right)\right)-\frac{e^{2\kappa}X}{x(\delta)}\right)2X & a r_k \end{vmatrix} > 0. \quad (47)$$

The sign of the matrix Δ_a is clearly positive as:

$$\Delta_a = \left(b'r_k(1-e)-1+e^{\kappa}\left(2-e^{\kappa}\right)+\frac{e^{2\kappa}\delta X}{x(\delta)}\right)2Xar_k > 0. \quad (48)$$

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

$$r_kK\frac{d\ln K}{d\ln b'} = \left(1-e^{\kappa}+e^{\kappa}\delta\right)X\frac{d\ln X}{d\ln b'}+e^{\kappa}\delta X\frac{d\ln \delta}{d\ln b'} < 0, \quad (49)$$

and

$$r_k K \frac{d\ln K}{d\ln a} = \left(1 - e^{\kappa} + e^{\kappa}\delta\right) X \frac{d\ln X}{d\ln a} + e^{\kappa}\delta X \frac{d\ln \delta}{d\ln a} > 0. \tag{50}$$

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.

8.3 Effect of Degree of Product Differentiation - Proposition 2

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

$$\frac{\partial \ln \delta}{\partial \ln e} = -\frac{\left(\left(2X - x\left(\delta\right)\right)\left(eb'r_k - 2\kappa e^{\kappa}\left(1 - e^{\kappa}\right)\right) x\left(\delta\right) - 2\kappa e^{2\kappa} X\left(2\left(\delta - 1\right) x\left(\delta\right) + X\right)\right)}{\left(c_1 r_k - 2e^{2\kappa} X\right) x\left(\delta\right)\delta}. \tag{51}$$

For very strong (weak) spillovers, i.e. low (high) values of κ holds: $\lim_{\kappa \to 0} \frac{\partial \ln \delta}{\partial \ln e} < 0$ and $\lim_{\kappa \to \infty} \frac{\partial \ln \delta}{\partial \ln e} < 0$. For intermediate values of spillovers, the sign of the derivative in Eq. (51) 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 $e = 0$:

$$\frac{\partial \delta}{\partial e}\Big|_{e=0} = -\frac{b'\left(2X - x\left(\delta\right)\right)}{c_1} < 0. \tag{52}$$

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

8.4 Robustness Checks

Table 7: Effect of $\Delta TRER_i$ on Innovation Using Alternative Measures of Differentiation

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

Table 8: Effect of $\Delta TRER_i$ for Firms that Do only One Type of Innovation

Dependent variable:	Only process innovation		Only product innovation	
	Probit	LPM	Probit	LPM
	(1)	(2)	(3)	(4)
$\lambda_s * \Delta TRER_i$	-0.183***	-0.179***	0.111***	0.102***
	(0.0426)	(0.0421)	(0.0268)	(0.0245)
$\Delta TRER_i$	0.529***	0.512***	0.247***	0.201***
	(0.1506)	(0.153)	(0.0728)	(0.0720)
Constant	yes	yes	yes	yes
$\Delta logNworkers_f$	yes	yes	yes	yes
Sector s fixed effects	yes	yes	yes	yes
Log-pseudolikelihood	-1343.687		-1051.554	
Pseudo R-squared	0.084		0.086	
R-squared		0.109		0.121
Observations	3,070	3,070	3,070	3,070

Table 9: Effect of $\Delta TRER_i$ on Innovation - Results Adding further Control Variables

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

Table 10: Effect on Innovation Using Alternative Measures of $TRER_{it}$

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

Table 11: Effect of $\Delta TRER_i$ on Innovation Using SUR

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

Table 12: Correlation between λ_s and Innovation Using World Bank Data for Brazil

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

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

8.5 Data Appendix

Figure 6: $\Delta TRER_i$ for Industries with Different Degrees of Product Differentiation

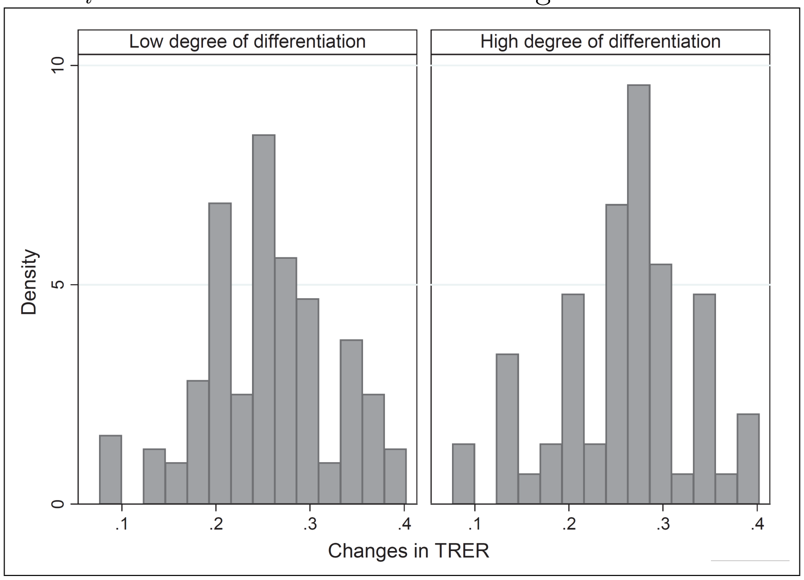

Table 13: Summary Statistics of Main Variables

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

Table 14: Description of the Dependent Variable and Main Explanatory Variables

Variable	Variable description	Data source
Innovation variables		
$\Delta Process_f$	$Process_f = 1$ if	PINTEC
	the firm reported process innovation, zero otherwise	
	(information available for the period 1998-2005)	
	(questions v10 and v11 from the surveys)	
$\Delta Product_f$	$Product_f = 1$ if	PINTEC
	the firm reported product innovation, zero otherwise	
	(information available for the period 1998-2005)	
	(questions v07 and v08 from the surveys)	
$\Delta Scope_f$	$Scope_f = 1$ if	PINTEC
	Innovation was important to increase product scope (question v78)[1]	
$\Delta Flexibility_f$	$Flexibility_f = 1$ if	PINTEC
	Innovation was important to increase product flexibility(question v83)[1]	
Exchange rates:		
$TRER_{it}$	Industry-specific exchange rates	NBER-UN
	$\sum_c \left(\left(0.5 \frac{X_t^{sc}}{\sum_c X_t^{sc}} + 0.5 \frac{M_t^{sc}}{\sum_c M_t^{sc}} \right) rer_t^c \right)$	and IMF
Degree of product differentiation:		
λ_s	Degree of product differentiation based on Khandelwal (2010)	Khandelwal (2010)
	λ_s is the average by sector s , defined according to the IBGE classification.	
λ_f	Degree of product differentiation based on Khandelwal (2010)	Khandelwal (2010)
	$\lambda_f = \frac{\sum_{fp} \lambda_{fp}}{N}$, where p is a HS 6-digit product exported by the firm.	
$ShDiff_s$	Share of differentiated products in s, following Rauch (1999)	Rauch (1999)
Firm initial characteristics:		
$FDI_{f,t=0}$	Foreign ownership dummy	PINTEC
$Nworkers_{f,t=0}$	Number of workers in f (measure of firm size).	RAIS-Brazil
$Skills_{f,t=0}$	Share of workers with tertiary education as a proxy for workers skills	RAIS-Brazil
$Ndestinations_{f,t=0}$	Number of export destinations	SECEX
$Nproducts_{f,t=0}$	Number of products exported	SECEX

Notes: 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. Questions answered according to their relative importance: (i) high, (ii) medium, (iii) low or (iv) does not apply. We assume that the variable is equal one (i.e., important) if the firm answered either (i) or (ii).