TRADING AWAY WIDE BRANDS FOR CHEAP BRANDS

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ABSTRACT. New findings from plant-level surveys show trade liberalization has opposite effects on product variety and cost reduction within firms. I explain the tradeoff between firm investments in product variety and cost reduction with a monopolistic competition model of brand differentiation. Firms can make many different products within a brand. When a firm introduces a new product, it eats its own market shares of existing products more than market shares of other firms. Import competition induces firms to ease intra-firm cannibalization by narrowing product variety. Foreign market access allows firms to make products cheaply by investing in cost-reducing processes. These conflicting forces provide sharp predictions for the effects of trade liberalization on investments in product variety and production processes of firms.

Examining Thai manufacturing firms, I show that intra-firm cannibalization is empirically relevant and trade liberalization has the predicted effects on product and process innovation during Thai tariff changes of 2003-2006. Thai tariff cuts reduce process innovation among exporters. Less export-oriented firms selling branded products increase product innovation while more export-oriented firms reduce product innovation in response to a Thai tariff cut. These results highlight the role of brand differentiation in unbundling the relationship between trade and innovation.

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1. INTRODUCTION

Multiproduct firms face competing needs for product variety and cost reduction. Firm reorientation between wide and cheap brands has substantial effects on industry-wide variety and productivity. New plant-level studies find trade liberalization has opposite effects on firm investments in product variety and cost reduction.[1] Standard models explain how economies of scale from trade enable firms to produce cheap brands by investing in process innovation. However, they do not address the tradeoff between wide and cheap brands. This paper addresses this tradeoff by modeling the joint decision of product variety and cost reduction. I show that brand differentiation provides a new channel through which trade affects innovation. As in other increasing returns to scale models, trade increases market access and allows firms to produce cheap brands through process innovation. At the same time, trade shrinks product variety offered by multiproduct firms. This is because the availability of foreign brands reduces the returns to product innovation. These conflicting forces provide sharp predictions of how trade affects firm investments in product variety and cost reduction. Examining Thailand's manufacturing sector, I estimate the impact of Thai trade policy from 2003 to 2006. Both reductions and increases in industry-level tariffs induce the theoretical tradeoff between wide and cheap brands.

I model the role of brand differentiation in product and process innovation of multiproduct firms. Firms can make multiple differentiated products within a brand. Brands are differentiated and consumers consider products to be more substitutable within brands than across brands.[2] For example, when Yoplait introduces a new yogurt, demand for its original yogurt falls more than demand for an original Dannon yogurt. I refer to this fall in demand as intra-firm cannibalization due to brand differentiation. Intra-firm cannibalization yields two new insights. First, it provides a new way of distinguishing product and process innovation. Second, it provides a new channel through which trade affects innovation, resulting in different effects on product and process innovation.

Departing from the standard focus on costs of innovation, I show that intra-firm cannibalization provides a new distinction between product and process innovation. When a firm widens its

[1] Within-firm product expansion accounts for about half of US output of new products (Bernard, Redding, and Schott 2008). Within-firm productivity growth accounts for two-thirds of total productivity gains among Spanish firms (Doraszelski and Jaumandreu 2007). Canadian firms cut back on their product lines and adopted more cost-reducing technologies as a result of the CUSFTA (Baldwin and Gu 2004, Baldwin and Gu 2005).

[2] See Broda and Weinstein (2007) for empirical evidence and Hui (2004) for supporting business and consumer psychology theories and evidence.

product range, its own market shares of existing products are cannibalized as consumers substitute into the firm's new products. In contrast, process innovation reduces the unit cost of making a product without cannibalizing existing market shares. Process innovation is characterized by economies of scale in the usual way; as quantity of a product rises, improvements in its production process become more profitable.

Moving beyond the effects of trade through economies of scale, I show that trade affects innovation through the new channel of intra-firm cannibalization. This explains why trade affects firm investments in product variety and cost reduction differently. As in standard models, moving from autarky to free trade provides a bigger market which has a positive effect on both product and process innovation through economies of scale. At the same time, trade intensifies product market competition. With brand awareness, firms cope with import competition by cutting back on product lines to ease cannibalization. After free trade, the typical firm makes fewer products at lower costs. Wide brands give way to cheap brands.

This wide-to-cheap effect of trade has conflicting implications for welfare from within-firm changes. Cheap brands increase welfare from lower prices while narrow brands lower welfare from variety. Product variety falls for another reason: exit of domestic firms due to tougher competition. The two forces of narrow brands and fewer firms lower domestic product variety, resulting in a welfare loss from domestic variety. This welfare loss is overcome by access to foreign products. Consequently, moving from autarky to free trade provides positive welfare gains from both variety and lower prices.

Similar changes take place in the empirically relevant case of a bilateral tariff liberalization. I show that a bilateral tariff reduction induces firms to move from wide to cheap brands. This explains the concurrent fall in product innovation and rise in technology upgrading of Canadian firms after the bilateral liberalization of CUSFTA. On the other hand, a unilateral home tariff reduction has the opposite effects; firms move from cheap to wide brands. A home tariff reduction reduces the market size available to home firms implying a rise in product innovation and a fall in process innovation. This cheap-to-wide effect is consistent with higher product innovation and shorter production runs of Indian firms following home tariff cuts of the nineties.[3]

[3]See Kochhar, Kumar, Rajan, Subramanian, and Tokatlidis (2006) and Goldberg, Khandelwal, Pavcnik, and Topalova (2008) which mentions that the Indian case does not conform to theoretical predictions of many recent multiproduct trade models.

To test the specific predictions of the wide and cheap effects, I focus on unilateral home tariff changes experienced by Thai manufacturing firms. Accounting for the reality of firm heterogeneity, I extend the wide and cheap effects to firms with different productivities. With a home tariff reduction, exporters lower process innovation due to a relative fall in home market size. A smaller market has lower competition implying less export-oriented firms face less competitive pressure than more export-oriented firms. More export-oriented firms have to ease cannibalization. They narrow their brands through lower product innovation. Less export-oriented firms widen their brands through more product innovation. I test these implications for Thai firms between 2002 to 2006. During this period, the Thai government unilaterally changed its tariffs. Home tariffs were increased in a few industries. However, most industries experienced a fall in home tariffs, resulting in an average fall of 42 per cent in Thai manufacturing tariffs. Considering Thai trade policy changes, I find empirical support for the relationship between trade liberalization and product and process innovation. As expected, exporters reduce process innovation in response to Thai tariff cuts. Among firms making branded products, less export-oriented incumbents increase product innovation while more export-oriented incumbents reduce product innovation with a fall in Thai tariffs.

To examine whether intra-firm cannibalization is at work in explaining these effects, I consider intra-firm demand linkages between products of Thai manufacturers in 2001-2002. Focusing on the product with highest sales for the establishment, I estimate demand as a function of price, industry-wide demand and demand for other products of the establishment. The demand estimates provide support for intra-firm cannibalization. Holding price and industry demand constant, demand for the main product falls by an average 0.1 per cent for every 1 per cent rise in demand for other products.

The focus on intra-firm demand linkages distinguishes this paper from related work. The innovation literature underlines how trade affects innovation through economies of scale (e.g., Atkeson and Burstein 2007, Lileeva and Trefler 2007 and Yeaple 2005). Considering the demand side, I show trade affects innovation through the new channel of intra-firm cannibalization. This is absent in recent work on the impact of trade on multiproduct firms. Bernard, Redding, and Schott (2006), Agur (2007) and Arkolakis and Muendler (2007) highlight the cost side of product innovation in multiproduct firms.[4] Looking at the demand side of product innovation, Mayer, Melitz, and Ottaviano (2009) consider the role of industry-wide demand conditions while Eckel and Neary (2005) and Feenstra and Ma (2007) emphasize demand linkages arising from strategic inter-firm competition among oligopolistic firms. Considering intra-firm demand linkages, I give a complementary explanation for the impact of trade liberalization on product innovation. Intra-firm cannibalization is important for innovation as many new products are closely related to existing products. For example, a survey of leading consumer product companies in the US found that 89 per cent of new product introductions were product line extensions such as a new flavor or package size, 6 per cent were brand extensions, and only 5 per cent were new brands (see Reddy, Holak, and Bhat 1994).

The paper is organized as follows. Section 2 introduces brand differentiation and examines the relationship between cannibalization, innovation and trade liberalization. In Section 3, I provide testable implications for trade liberalization and innovation by extending the model to heterogeneous firms. Section 4 briefly discusses innovation and trade policy in the Thai context. I test the implied relationship between innovation and trade liberalization and discuss evidence for intra-firm cannibalization in Section 5. Section 6 concludes.

2. Theoretical Model

This Section provides a multiproduct linear demand model with two key features. First, product and process innovation differ through intra-firm cannibalization. Second, trade affects both product and process innovation. This second feature does not arise in the standard nested CES model of multiproduct firms. Following Allanson and Montagna (2005), I consider multiproduct extensions of Krugman (1980) and Melitz (2003). In the Appendix, I show that nested CES preferences imply trade liberalization has no effect on within-firm product and process innovation in Krugman (1980) and on process innovation in Melitz (2003). CES preferences are special in inducing all adjustment through the extensive margin. Departing from CES preferences, I consider a linear demand system. Starting with a discussion of innovation in the closed economy, I proceed to the open economy and show that trade has conflicting effects on product and process innovation.

[4]These papers consider nested CES preferences which exogenously fixes the rate of intra-firm cannibalization implying trade has no impact on innovation through the cannibalization channel. Similarly, related work on quality underlines differences in the costs of upgrading quality and productivity (e.g. Kugler and Verhoogen 2007, Hallak and Sivadasan 2006).

2.1. **Multiproduct Linear Demand Model: Closed Economy.** Consider a closed economy with L identical agents, each endowed with a unit of labor. Total income in the economy is $I = wL$ where w is the wage rate (normalized to 1). Agents work in one of two industries: a homogeneous goods industry or a differentiated goods industry. In the homogeneous goods industry, producers are perfectly competitive and produce under constant returns to scale with a unit labor requirement. In the differentiated goods industry, firms are monopolistically competitive and enter by paying a cost f. By paying this entry cost, firms can produce multiple products within a brand. I explain the role of brands in the following subsection and then consider its implications for cannibalization and innovation.

2.1.1. *Consumers.* Agents in the home country have identical preferences defined over a homogeneous and a differentiated good. Agent k consumes q_0^k of the homogeneous good and q_{ji}^k of product $i \in \Omega_j$ of brand $j \in J$ of the differentiated good. Her total consumption of brand j goods is $q_j^k \equiv \int_i q_{ji}^k di$. Her industry-wide consumption of differentiated goods of all brands is $Q^k \equiv \int_j q_j^k dj$. Agent k derives the following utility from her consumption of homogeneous and differentiated goods:

$$U^k \equiv q_0^k + \alpha Q^k - \frac{\delta}{2}\int_j \int_i (q_{ji}^k)^2 di dj - \frac{\gamma}{2}\int_j (q_j^k)^2 dj - \frac{\eta}{2}(Q^k)^2 \tag{2.1}$$

Parameters α, δ, γ and η are all positive. Equation (2.1) is a multiproduct version of quasilinear preferences used in Melitz and Ottaviano (2008). Parameters α and η determine substitutability between the homogeneous and differentiated goods. Parameter δ captures the degree of differentiation across products. Lower δ implies products are less differentiated and hence more substitutable with $\delta = 0$ denoting consumers have no taste for diversity in products. Parameter γ captures the degree of differentiation across brands with $\gamma = 0$ implying no brand differentiation. This is a novel feature of the preference structure which I discuss in detail below.

Let q_{ji} be the total demand for brand j's product i across all agents. With identical agents, each agent k demands $q_{ji}^k = q_{ji}/L$. In an equilibrium where agents consume both homogeneous and differentiated goods,[5] the inverse demand function is $p_{ji} = \alpha - \delta q_{ji}^k - \gamma q_j^k - \eta Q^k$. Substituting for q_{ji}^k, total demand for brand $j's$ product i is

$$q_{ji} = \frac{L}{\delta}[\alpha - p_{ji} - \gamma q_j/L - \eta Q/L] \tag{2.2}$$

[5]See Appendix for sufficient conditions to ensure a well-defined equilibrium.

where $q_j \equiv Lq_j^k$ and $Q \equiv LQ^k$. I illustrate the role of brand differentiation through cross-elasticities implied by Demand (2.2). Within-brand cross elasticity of product i with respect to any other product $k \neq i$ of the same brand j is $\varepsilon_{ji,jk} \equiv -(dq_{ji}/dq_{jk})(q_{jk}/q_{ji}) = (\gamma + \eta)(q_{jk}/\delta q_{ji})$. Across-brand cross elasticity of brand j's product i with respect to any product k of any other brand $l \neq j$ is $\varepsilon_{ji,lk} \equiv -(dq_{ji}/dq_{lk})(q_{lk}/q_{ji}) = \eta(q_{lk}/\delta q_{ji})$.

In the special case when $\gamma = 0$, within-brand cross elasticity is the same as across-brand cross elasticity. Consumers of a new Yoplait yogurt are indifferent between the original Yoplait and the original Dannon yogurt. This special case corresponds to the demand specification of Melitz and Ottaviano (2008). Following the marketing and industrial organization literature, I assume consumers consider products to be more substitutable within brands rather than across brands.[6] This brand awareness is embodied in a positive γ. When $\gamma > 0$, within-brand cross elasticity exceeds across-brand cross elasticity ($\varepsilon_{ji,jk} > \varepsilon_{ji,lk}$). An increase in consumption of the new Yoplait yogurt reduces demand for the original Yoplait more than demand for the original Dannon. I refer to this fall in demand due to brand differentiation as intra-firm cannibalization.

2.2. **Firms.** Having explained brand differentiation, I examine firm decisions in the differentiated goods industry and show how cannibalization distinguishes product and process innovation. I start with firm decisions in the simplest case of symmetric firms in autarky.

In the differentiated goods industry, firms enter freely by paying a cost f. After paying entry costs, they can make products at a unit cost c. Firms have perfect information of the unit cost before paying entry costs. Having paid the entry cost, each firm faces three choices: which production process to use, what quantity to produce and how many products to supply. Firm j can either make product i at the unit cost c or choose a lower unit cost $c(\omega_{ji})$ by investing in process ω_{ji}. Higher levels of ω_{ji} correspond to lower levels of unit cost ($c'(\omega_{ji}) < 0$) with $c(0) = c$ denoting no process innovation. Upgrading to process ω_{ji} entails expenditure on technology adoption or investment in process R&D at a rate r_ω. Firm j chooses how much of product i to supply to the home market (q_{ji}). It chooses this quantity faced with the following inverse demand function:

$$p_{ji} = (\alpha - \eta Q/L) - \delta q_{ji}/L - \gamma q_j/L \equiv a - \delta q_{ji}/L - \gamma q_j/L \tag{2.3}$$

[6]E.g., Aaker (1991), Boush and Loken (1991) and Boush (1993) in marketing; Anderson, De Palma, and Thisse (1992) and Broda and Weinstein (2007) in industrial organization.

The inverse demand intercept $a \equiv \alpha - \eta Q/L$ summarizes industry demand conditions that firm j takes as given. Firm j can make multiple products within a brand and chooses how many products to make. It offers a product range of h_j products by investing in product R&D at a rate r_h per product.

Putting these choices together, firm j decides on its production process ω_{ji} and quantities q_{ji} for each product i along with its product range h_j to maximize the following profit function.

$$\max_{\{\omega_{ji}, q_{ji}\}_i, h_j} \Pi_j \equiv \int_0^{h_j} \{[p_{ji} - c(\omega_{ji})]q_{ji} - r_\omega \omega_{ji} - r_h\} di - f$$

With symmetric costs within firms, firm j chooses the same process and quantities for each product supplied and the firm-product subscripts can be suppressed.[7] Consequently, the firm problem can be re-written as

$$\max_{\omega,q,h} \Pi = h\{[p - c(\omega)]q - r_\omega \omega - r_h\} - f \equiv h\pi - f$$

where π is the profit per product. Note that firms face no uncertainty of costs or payoffs and no new information is revealed at any stage. As a result, the sequencing of firm decisions does not matter. In what follows, I determine the optimal production process ω, quantity q and product range h through FOCs for the firm problem.

2.2.1. *Production Process.* The FOC for process choice is $\partial\pi/\partial\omega = -c'(\omega)q - r_\omega = 0$. A firm invests in process R&D until savings from lower unit costs (net of the process R&D cost) are driven to zero. Two points are worth mentioning. First, process innovation ω reflects economies of scale through q. As scale per product rises, process innovation becomes more profitable. Second, process innovation does not directly cannibalize. Given its other decisions (q in this case), this firm would have chosen the same process in the absence of intra-firm cannibalization (when $\gamma = 0$).

For the remainder of this Section, I specify $c(\omega) = (1 - \omega^{1/2})c$ where $\omega \in (0, 1)$. The specific form is not crucial but provides clear solutions to highlight the main results. With this specific form, optimal process choice is $\omega = (cq/2r_\omega)^2$.

2.2.2. *Quantity.* With symmetric quantities, total supply of firm j is $q_j = \int_i q_{ji} di = hq$. This implies the inverse demand of Equation (2.3) is $p = a - \delta q/L - \gamma hq/L$. Quantity q lowers consumers' willingness to pay through its individual effect ($\delta q/L$) and its brand-wide effect ($\gamma hq/L$). The FOC

[7] Assuming joint concavity of the profit function in quantity and process, firms prefer to spread their production evenly over products. For clarity, I abstract from within-firm heterogeneity and rising costs of product innovation.

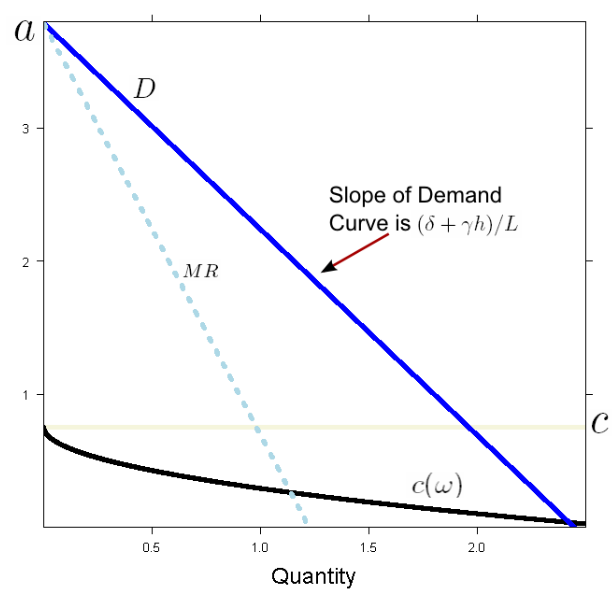
for quantity supplied to the domestic market is

$$\frac{\partial \pi}{\partial q} = \underbrace{[p - c(\omega)] - \delta q/L}_{\text{Own MR=MC}} - \underbrace{\gamma h q/L}_{\text{Cannib. Effect}} = 0 \tag{2.4}$$

The first term ensures own marginal revenue of a product equals its marginal cost. The second term is specific to multiproduct firms and would be zero in the absence of intra-firm cannibalization (when $\gamma = 0$). It shows multiproduct firms reduce their quantities in anticipation of cannibalization of old products.

Figure 2.1 plots the inverse demand function for the home market. The x-axis reports quantities while the y-axis reports prices, marginal revenue and unit costs in terms of units of the numeraire good. The inverse demand function D is linear with an intercept a. Its slope is $(\delta + \gamma h)q/L$, as opposed to $\delta q/L$ for single-product firms. Multiproduct firms perceive the effects of increasing quantity on demand for their other products implying the slope includes $\gamma h q/L$. The optimized unit cost function $c(\omega)$ is downward-sloping as higher quantities make it more profitable to undertake process innovation. As usual, optimal quantity per product is determined by the intersection of the marginal revenue curve MR and the marginal cost curve $c(\omega)$. The difference is that the slope of the marginal revenue curve reflects the own price effect and the brand-wide effect on revenue from other products.

FIGURE 2.1. Optimal Quantity per Product



From Equation (2.4) and the inverse demand, optimal quantity is $q = L(a - c(\omega))/2(\delta + \gamma h)$. Substituting for the optimal process choice ω, optimal quantity is $q = (a - c)/2[(\delta + \gamma h)/L - c^2/4r_\omega]$. At this optimal quantity, the perceived price elasticity is

$$\varepsilon = -\frac{p}{q}\frac{dq}{dp} = \frac{2}{1 - c/a}\left(1 - \frac{c^2/4r_\omega}{(\delta + \gamma h)/L}\right)$$

As usual, markup ($\mu \equiv p - c(\omega)$) is inversely proportional to the perceived price elasticity of demand implying $\mu = p/\varepsilon$. Markups and perceived elasticity reflect two key features. First, multiproduct firms face higher elasticities and choose lower markups due to cannibalization (through γh). When a firm introduces a new product, demand for its existing products falls. With linear demand for each of these products, this implies a rise in demand elasticity. Second, markups and elasticities respond to industry demand conditions a. As industry conditions deteriorate (i.e. a falls), the demand curve shifts inward implying a rise in demand elasticity. Firms perceive this rise in demand elasticity and respond by lowering markups.

2.2.3. *Product Range.* Firms decide on the mass of products to be supplied to the market. The FOC for product range h is

$$\frac{\partial \Pi}{\partial h} = \pi - \underbrace{h(\gamma q/L)q}_{\text{Cannib. Effect}} = 0 \tag{2.5}$$

The optimal product range equates the variable profit from a new product π to the fall in profit from cannibalization of old products. The new product reduces price of each old product by $dp/dh = \gamma q/L$, resulting in total cannibalization of $h(\gamma q/L)q$.

Given other firm decisions (q and ω), net marginal benefit from the new product falls with intra-firm cannibalization γ. Unlike process innovation, product innovation directly cannibalizes. Formally, $\partial h(q, \omega, \gamma)/\partial\gamma < 0$ while $\partial\omega(q, \gamma)/\partial\gamma = 0$.

Examining intra-firm demand linkages further, product innovation can be interpreted as an instrument for firms to adjust demand elasticities. A new product gives profit π. At the same time, it increases perceived demand elasticity ε of old products. Equation (2.5) can be expressed as a tradeoff between profits from a new product and higher elasticities of all old products i.e. $\pi = h\pi'(\varepsilon)\partial\varepsilon/\partial h$. Product innovation enables the firm to adjust its demand elasticities to a desired level. A similar interpretation is given to "perceived quality" in the advertising literature (e.g. Dixit 1979).

2.3. **Equilibrium Outcomes in Autarky.** Having determined firm decisions, I discuss equilibrium outcomes in autarky and show that cannibalization effects distinguish product and process innovation in the general equilibrium.

Profit per product is $\pi = [p - c(\omega)]q - r_\omega \omega - r_h$. Substituting for optimal markups and process $\omega = (cq/2r_\omega)^2$, profit per product is $\pi = (\delta + \gamma h)q^2/L - (c^2/4r_\omega)q^2 - r_h$. A firm introduces new products till the profit from a new product net of its cannibalizing effect is driven to zero. Consequently, Equation (2.5) can be summarized as a zero-profit condition (ZPC) given below:

$$\pi - \gamma h q^2/L = (\delta/L - c^2/4r_\omega)q^2 - r_h = 0 \tag{ZPC}$$

The ZPC determines equilibrium quantity per product to be $q^{\text{aut}} = r_h^{1/2}/(\delta/L - c^2/4r_\omega)^{1/2}$. As product R&D becomes more expensive (i.e. r_h rises), firms choose to increase quantities rather than products implying q and r_h are positively related. As process R&D becomes more expensive (i.e. r_ω rises), firms find it less profitable to upgrade their production process implying q and r_ω are negatively related. Optimal quantity q rises with market size L implying scale per product is higher in bigger markets.

Process innovation in autarky is $\omega^{\text{aut}} = [cq^{\text{aut}}/2r_\omega]^2 = (c/2r_\omega)^2 r_h/(\delta/L - c^2/4r_\omega)$. It is independent of the degree of cannibalization γ, i.e. $d\omega^{\text{aut}}/d\gamma = 0$. Earlier, I showed that process innovation does not directly cannibalize (given q). Now it can be seen that process innovation does not cannibalize even after taking other firm decisions into account (q^{aut} in this case). The first implication is that process innovation has no cannibalization effects in a partial equilibrium when all firm decisions are taken into account but industry-wide demand conditions are fixed. The second implication is that process innovation does not have cannibalization effects in a general equilibrium setting when industry-wide demand conditions are determined endogenously. This follows from the fact that process innovation is independent of industry-wide demand conditions.

The independence of process innovation from industry-wide demand can be explained as follows. Suppose firm j upgrades the production process for a given product i. This does not directly affect demand for product i or other products of firm j. However, the firm has an incentive to lower price of product i in order to sell a higher amount of it. With increased sales of product i, consumers demand less of other products produced by firm j. Intra-firm cannibalization increases implying firm j's marginal product is no longer profitable. It must re-adjust its product lines. Under full readjustment, firm j cuts product lines to reduce intra-firm cannibalization and gets back at the original optimal level of cannibalization. Firm j's total supply and hence its cannibalization burden are unchanged after process innovation. As a result, cannibalization does not play a role in process innovation directly or indirectly through higher quantities.

Unlike process innovation, product innovation cannibalizes directly and indirectly (i.e. $dh^{\text{aut}}/d\gamma < 0$). I determine the optimal product range and then discuss its cannibalizing effect. In equilibrium, free entry ensures each firm earns zero profits implying $\Pi = h\pi - f = 0$. From Equation (2.5), firms ensure that profit per product π equals the cannibalization effect $\gamma hq^2/L$. Consequently, the free entry condition (FE) can be summarized as:

$$\text{(FE)} \qquad h\pi = \gamma h^2 q^2/L = f$$

Substituting for q from the ZPC condition, the FE condition shows product range in autarky is $h^{\text{aut}} = [Lf/\gamma(q^{\text{aut}})^2]^{1/2} = [Lf(\delta/L - c^2/4r_\omega)/\gamma r_h]^{1/2}$ implying firms make fewer products when faced with higher intra-firm cannibalization γ. This shows that product innovation cannibalizes in general equilibrium. For completeness, I note that product innovation has cannibalizing effects in partial equilibrium too. The reason is that the direct cannibalization effect is not wiped out by any countervailing adjustments in quantity. I summarize the cannibalization results in Proposition 1.

Proposition 1. *Product innovation cannibalizes directly and indirectly while process innovation does not. Formally,* $\partial h(q,\omega,\gamma)/\partial\gamma < 0$ *and* $dh/d\gamma < 0$ *while* $\partial\omega(q,\gamma) = d\omega/d\gamma = 0$*.*

Having determined the equilibrium process, quantity and product range, I discuss the equilibrium mass of firms operating in the market. Total quantity of all firms in the market is $Q = Mhq$ implying the inverse demand function is $p = \alpha - \eta Mhq/L - \delta q/L - \gamma hq/L$. Equating the inverse demand function to the optimal price chosen by the firm, the mass of firms can be written in terms of the optimal quantity and product range as $M^{\text{aut}} = L[(\alpha - c)/q^{\text{aut}} + c^2/2r_\omega - 2(\delta + \gamma h^{\text{aut}})/L]/\eta h^{\text{aut}}$. The reader may verify that the mass of firms increases with L implying that bigger markets have more firms. Moreover, the mass of available products Mh increases with L showing that bigger markets have higher product variety. Even though the product range h^{aut} declines with L, total product variety increases due to more firms operating in bigger markets.

2.4. **Open Economy.** Having discussed equilibrium outcomes in autarky, I examine how trade affects different types of innovation. Consider two identical countries, Home and Foreign (denoted by $*$). Following Melitz and Ottaviano (2008), suppose that home and foreign markets for differentiated goods are segmented. The homogeneous good is traded freely implying trade in differentiated goods need not be balanced. I first consider the simple case where the economy moves from autarky to free trade and study the channels through which trade affects innovation. Then I discuss the impact of tariff liberalization.

2.4.1. *Equilibrium in an Open Economy.* With free trade, the firm problem is similar but now firms also decide on the quantities q^x_{ji} of each product for the foreign market. As in Melitz and Ottaviano (2008), there are no fixed costs of exporting and the firm problem can be specified as follows:

$$\max_{\{\omega_{ji}, q_{ji}, q^x_{ji}\}_i, h_j} \Pi_j \equiv \int_0^{h_j} \{[p_{ji} - c(\omega_{ji})]q_{ji} + [p^x_{ji} - c(\omega_{ji})]q^x_{ji} - r_\omega \omega_{ji} - r_h\} di - f$$

In the Appendix, I show that firms choose to supply the same product range to both home and foreign markets implying both $q_{ji}, q^x_{ji} > 0$ for $i \in [0, h_j]$. As earlier, firm j chooses the same process and quantities for each product and the firm-product subscripts can be suppressed.

The FOCs for the firm problem are similar to those in autarky. From the firm's FOC for process choice, optimal production process is $-c'(\omega)(q + q^x) = r_\omega$. Optimal quantities for the home and foreign markets are $q = (a - c)/2[(\delta + \gamma h)/L - c^2/4r_\omega]$ and $q^x = (a^* - c)/2[(\delta + \gamma h)/L - c^2/4r_\omega]$ where a^* denotes industry demand conditions in the foreign market. The FOC for product range is $\pi - h(\gamma q/L)q - h(\gamma q^x/L)q^x = 0$ which shows that firms account for cannibalization incurred in both the home and foreign markets. As earlier, substituting for optimal process and quantities in the FOC for product range gives the ZPC condition under free trade. Optimal process and quantities transform the ZPC condition to $\pi - \gamma h q^2/L + \gamma h(q^x)^2/L = (\delta/L)(q^2 + (q^x)^2) - (c^2/4r_\omega)(q + q^x)^2 - r_h = 0$. With identical countries and free trade, firms supply the same quantity to each market ($q^x = q$). Total quantity is $2q$ per product and the ZPC under free trade simplifies to:

$$\text{(ZPC')} \qquad (\delta/2L - c^2/4r_\omega)(2q)^2 - r_h = 0$$

The ZPC′ condition determines equilibrium quantity per product to be $2q = r_h^{1/2}/(\delta/2L - c^2/4r_\omega)^{1/2}$. Total quantity per product $2q$ rises providing economies of scale to increase process innovation to $\omega^{\text{open}} = [c(2q)/2r_\omega]^2 = (c/2r_\omega)^2 r_h/(\delta/2L - c^2/4r_\omega) > \omega^{\text{aut}}$.

The equilibrium product range can be determined by the free entry condition. In equilibrium, free entry ensures profit from home and exports sales is driven to zero implying the FE condition is now given by $h\pi = \gamma h^2 q^2/L + \gamma h(q^x)^2/L = f$. Substituting for $q^x = q$, the FE condition under free trade simplifies to

(FE′) $$h\pi = \gamma h^2(2q)^2/2L = f$$

Substituting for optimal q from the ZPC′ condition, FE′ shows that product innovation drops to $h^{\text{open}} = [2Lf/\gamma(2q)^2]^{1/2} = [2Lf(\delta/2L - c^2/4r_\omega)/\gamma r_h]^{1/2} < h^{\text{aut}}$.

The ZPC′ and FE′ conditions show that opening the economy to free trade is equivalent to a rise in the size of an autarkic economy (from L to $2L$). The equilibrium outcomes are similar to those in a bigger market. Scale per product $2q$ and process innovation are higher while product innovation is lower after trade. Trade increases process innovation through economies of scale from a bigger market. Trade reduces product innovation due to higher competition from entry of foreign firms. As shown in the free entry condition, firms adjust to entry of foreign firms by narrowing the product range. I discuss the underlying economic reason for this in the next subsection.

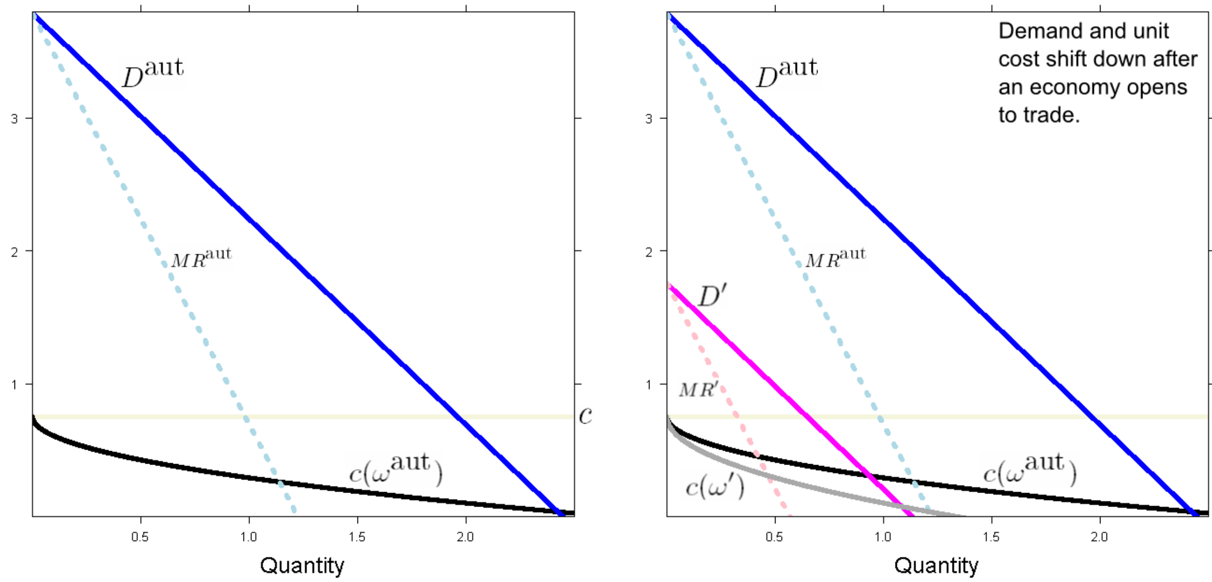
2.4.2. *Impact of Trade on Innovation.* As in Krugman (1980), trade increases the size of the home market. Rise in market size through trade produces two effects: a market expansion effect and a product market competition effect. Trade gives access to a new market. At the same time, trade results in entry of foreign firms which intensifies product market competition. The market expansion and competition effects have opposing implications for firm decisions and their relative strength determines how trade affects product and process innovation.[8]

The market expansion effect of trade on product and process innovation is straightforward. Trade provides firms with an opportunity to sell to the foreign market. This implies firms can increase their total quantity of each individual product as well as the marginal product. Consequently, access to foreign market provides firms with an incentive to increase both product and process innovation.

Regarding the competition effect, we can trace out its implications through the demand function faced by a firm. When the home economy opens to trade, foreign firms anticipate higher profitability through exports and enter the home market. As the mass of suppliers M rises, industry-wide consumption $Q = Mhq$ increases. This lowers the demand intercept $a \equiv \alpha - \eta Q/L$, leading to a drop in home demand for firm j's product i. Figure 2.2 illustrates the changes in home demand for a given product. For ease of reference, Panel A shows the demand curve in autarky and Panel B

[8]The role of import competition is borne out by recent studies showing that industry productivity and product dropping by firms are negatively related to imports (e.g. Acharaya and Keller 2008 and Liu forthcoming).

FIGURE 2.2. Direct Impact of Trade on Residual Home Demand



(A) Autarky (B) Free Trade

shows the change in demand after trade. Entry of foreign firms reduces a so the residual demand curve faced by a firm shifts down from D^{aut} to D'.

With tougher competition at home, firms can only sell a lower quantity in the home market. Unlike the CES case, firms respond to their declining home market share by lowering markups. Consequently, the drop in home demand falls short of the rise in exports. Total quantity per product ($q + q^x = 2q$) increases after trade providing firms with higher economies of scale. Total quantity per product rises for another reason. As shown in Figure 2.2 B, the marginal cost curve shifts down from $c(\omega^{\text{aut}}) = c(\omega(q))$ to $c(\omega') = c(\omega(q + q^x))$. Firms export to the foreign market ($q^x > 0$) implying they can produce less quantity q for the home market to get the same reduction in unit cost. Total quantity per product rises making it more profitable for firms to undertake process innovation.

With access to the foreign market, firms can export each product. Exports increase profit per product but at a rate lower than the original markup in autarky. Trade worsens industry demand conditions, resulting in lower a and hence higher demand elasticities. With higher demand elasticities after trade, firms are forced to lower their markups so profit per product falls. On the other hand, cannibalization increases due to higher quantity per product $q + q^x$. As a result, net profit from the marginal product drops and firms must cut back on products. Unlike the CES case, trade increases elasticities and firms counteract the rise in elasticities by cutting product lines.

Lower product innovation reduces the mass of domestic products at home. Domestic variety falls for another reason, exit of domestic firms M^d due to worse home market conditions. This puts further downward pressure on domestic product variety $M^d h$ available at home. However, home consumers do not experience a reduction in total available variety. They gain access to products of foreign firms. Total product variety Mh available to home consumers rises, resulting in welfare gains from increase in variety.

As mentioned earlier, this increase in products available at home lowers residual demand and induces firms to lower their markups. Reduction in markups is accompanied by greater process innovation. Both these forces put downward pressure on prices. Prices fall after trade and provide welfare gains from lower prices. I summarize these results in Proposition 2 below.

Proposition 2. *Opening the economy to trade reduces product innovation and increases process innovation. At the aggregate level, Gains from Variety and Gains from Lower Prices are both positive.*

2.4.3. *Bilateral and Unilateral Tariff Changes.* I examine the empirically relevant cases of bilateral and unilateral tariff changes. Consider a foreign tariff t^* and a home tariff t on differentiated goods. A foreign tariff t^* increases the unit cost of exporting from $c(\omega)$ to $c(\omega) + t^*$ for home firms. A home tariff t increases the unit cost of exporting from $c(\omega)$ to $c(\omega) + t$ for foreign firms. Following Nocke and Yeaple (2005), I consider tariff changes evaluated in an interior equilibrium starting from $t = t^* > 0$.

When faced with a foreign tariff t^*, a home firm supplies a lower quantity to the foreign market implying $q^x < q$. Though firms export less when faced with foreign tariffs, trade still provides an increase in home market size. Let the export to home production ratio be $\theta \equiv q^x/q$. Then trade increases the market size of a closed home economy from L to sL where the size factor is $s \equiv (1+\theta)^2/(1+\theta^2)$. The ZPC′ and FE′ curves are given by

$$(\delta/sL - c^2/4r_\omega)(q(1+\theta))^2 - r_h = 0 \tag{ZPC′}$$

$$\gamma h^2 (q(1+\theta))^2/sL = f \tag{FE′}$$

The ZPC′ condition shows that total quantity per product $q(1+\theta)$ increases due to a rise in market size from L to sL. Substituting for equilibrium $q(1+\theta)$, the FE condition shows that product range

h narrows after trade. Compared to free trade, θ is no longer 1 and the size factor s varies with tariffs.

As earlier, the FOCs for supply to the home and foreign markets (q and q^x) imply $q = (a - c)/2[(\delta + \gamma h)/L - c^2/4r_\omega]$ and $q^x = (a^* - t^* - c)/2[(\delta + \gamma h)/L - c^2/4r_\omega]$. The only difference compared to free trade is that t^* is no longer zero and firms must pay an additional per unit cost to supply to the foreign market. As the denominators for optimal q and q^x are the same, export to home production ratio $\theta \equiv q^x/q$ simplifies to $\theta = (a^* - t^* - c)/(a - c)$. The export to home production ratio θ captures the degree to which a firm is able to increase its market size through relative access to the foreign market. As θ rises, size factor s rises implying firms experience a relative increase in the market size available to them. For brevity, details of the relationship between size and tariff changes are discussed in the Appendix and a summary is provided here.

A bilateral tariff liberalization reduces tariffs in both countries. With the same tariffs at home and abroad $t = t^*$, industry-wide demand conditions are also the same in each country implying $a = a^*$ and $\theta = (a - t - c)/(a - c)$. I discuss the effects of a bilateral tariff cut on the home economy. A similar argument holds for the foreign economy. The direct impact of a bilateral tariff cut is a rise in θ (given a). With a rise in θ, home firms expect a rise in market size available to them. This encourages entry in the home economy. Competition rises in the home market resulting in a deterioration in industry-wide demand conditions a. The indirect impact of a fall in a reinforces the rise in market size through θ. As in the free trade case, the rise in market size following a bilateral tariff liberalization reduces product innovation through greater competitive pressure and increases process innovation through economies of scale.

A unilateral foreign tariff (t^*) cut reduces the tariff faced by home exporters in the foreign country. The direct impact of a unilateral foreign tariff cut is a rise in θ (given a and a^*). With a rise in θ, home firms expect a rise in market size available to them. This encourages entry and competition, resulting in a deterioration in industry-wide demand conditions a. The opposite effect takes place in the foreign market. Foreign firms expect a fall in market size available to them due to higher exports by home firms. This induces exit in the foreign economy. Competition falls in the foreign market resulting in an improvement in industry-wide demand conditions a^*. The indirect impact of a fall in a and a rise in a^* reinforces the rise in market size through θ. As in the free trade case, the rise in market size following a unilateral foreign tariff liberalization reduces product innovation and increases process innovation.

A unilateral home tariff (t) cut reduces the tariff faced by foreign exporters in the home country. Let the foreign export to foreign production ratio be $\theta^* \equiv (q^x)^*/q^* = (a - t - c)/(a^* - c)$. A unilateral home tariff cut does not have any direct impact on θ but does have a direct impact on the foreign θ^*. A fall in home tariff t directly increases θ^*. With a rise in θ^*, foreign firms expect a rise in market size available to them. This encourages entry in the foreign economy. Competition rises in the foreign market resulting in a deterioration in industry-wide demand conditions a^*. The opposite effect takes place in the home market. Home firms expect a fall in market size available to them due to higher home imports. This induces exit in the home economy, resulting in an improvement in industry-wide demand conditions a. The indirect impact of a fall in a^* and a rise in a reinforces the rise in market size through θ^*. Foreign firms experience a rise in market size. In contrast, home firms experience a fall in market size due to the indirect impact of a fall in a^* and a rise in a. Compared to free trade, a unilateral home tariff reduction has the opposite effects; market size for home firms shrinks implying they move to wide brands produced with less investment in process R&D. I summarize these results in Proposition 3.

Proposition 3. *With a bilateral or foreign tariff reduction, home firms reduce product innovation and increase process innovation. A home tariff reduction has the opposite effects.*

As mentioned earlier, this result is consistent with a concurrent fall in product innovation and rise in technology upgrading of Canadian firms during CUSFTA. It provides a new explanation for the fall in product innovation of US firms due to CUSFTA (Bernard, Redding, and Schott 2006). It explains the rise in product innovation and reduction in scale of Indian firms following home tariff liberalization in the nineties.

3. Theoretical Extension: Firm Heterogeneity

Section 2 shows how trade liberalization affects product and process innovation in a typical firm. As is well-known, there is substantial firm heterogeneity within industries. Recent empirical work finds innovation responses vary systematically across firms.[9] To explain these differences, I extend Proposition 3 to heterogeneous firms and provide testable predictions regarding trade liberalization and innovation.

As earlier, firms pay an entry cost f to obtain a unit cost draw c. The cost draw is no longer deterministic. I abstract from within-firm heterogeneity and assume each firm obtains a single

[9] E.g., small Canadian firms lowered product innovation while large Canadian exporters increased product innovation during CUSFTA (Baldwin and Gu 2005).

cost draw. Firms know the distribution of costs $c \sim G(c)$ defined on the support $[0, c_M]$. They do not observe the realizations before paying the entry cost. Having paid the entry cost, firms observe all cost draws. Then they decide whether to stay in the market or to exit immediately. No new information is revealed after the decision to stay.

If a firm stays, it decides on its process, quantities and product range. In this sub-section, I consider discrete changes in technology for simplicity and empirical conformity. A firm with initial cost draw c can upgrade its process to $c - \omega(c)$ by paying r_ω. It chooses its production process ω, quantities (q, q^x) and product range h to maximize the following profit function:

$$\max_{\omega,q,q^x,h} \Pi(c) = h[(p - c + 1_{\omega>0}\omega(c))q + 1_x(p^x - c + 1_{\omega>0}\omega(c) - t^*)q^x - 1_{\omega>0}r_\omega - r_h]$$

where $1_{\omega>0} = 1$ if a firm invests in process innovation ($\omega(c) > 0$) and 0 otherwise.

As in Melitz and Ottaviano (2008), firms decisions vary by productivity. The least productive firms exit the home market and the most productive firms produce for both the home and foreign markets. As in Melitz and Ottaviano (2008), the linear demand system ensures exporters are more productive even though there are no fixed costs of exporting. Optimal choices of process, quantities and products are determined in a manner similar to Section 2. Consequently, I relegate details to the Appendix and proceed to a discussion of the impact of trade liberalization on innovation.

3.1. **Trade Liberalization and Export Orientation.** Moving from autarky to free trade is once again equivalent to an increase in market size of the home economy. But now the rise in market size differs across firms. Continuing non-exporters do not experience any market expansion. Consequently, they operate at the same scale and do not change their process decisions. Instead, they are adversely affected by tougher competition in the home market (due to a fall in aggregate home market conditions a). They respond by cutting back on product lines.

Exporters experience an expansion in market size and engage in greater process innovation. At the same time, they face tougher competition at home. The relative strength of the market expansion and competition effects in determining product innovation depends on the export orientation of firms. Let the export to domestic production ratio of a firm be denoted by $\theta \equiv q^x/q$. Average export orientation of the home economy ($\tilde{\theta}$) is defined as the ratio of total exports to domestic supply of home firms. Let M^d and M^x denote the mass of home firms supplying to home and foreign markets respectively. Then $\tilde{\theta} \equiv M^x \int h(c)q^x(c)g(c)dc / M^d \int h(c)q(c)g(c)dc$. The cutoff $\tilde{\theta}$ categorizes firms into small and large exporters. By definition, small exporters have a lower-than-average export to domestic production ratio ($\theta < \tilde{\theta}$) while large exporters have a higher-than-average export to domestic production ratio ($\theta \geq \tilde{\theta}$).

Small exporters supply predominantly to the home market where competition has become more intense. Market expansion through trade is not enough to undo their loss from worse home market conditions. As a result, small exporters ease cannibalization by cutting back on product lines to counteract the rise in demand elasticities. Large exporters are the big gainers from market expansion. They are able to corner a large fraction of the export market. This is sufficient to undo the adverse effects of tougher competition at home. Consequently, large exporters experience a rise in profitability of their marginal product and are able to absorb higher intra-firm cannibalization. Large exporters add more product lines, resulting in a rise in their product innovation.

As earlier, a bilateral tariff liberalization, a fall in foreign tariff or a rise in home tariff increases the market size available to home firms and produces effects similar to free trade. A bilateral tariff liberalization provides bilateral access to markets and acts like an increase in market size for home and foreign firms. A unilateral foreign tariff cut or a unilateral home tariff increase differs in its effects on industry demand conditions at home and abroad but results in similar effects on innovation. With a unilateral foreign tariff cut or home tariff rise, home market conditions deteriorate (i.e. a falls) while foreign market conditions improve (i.e. $a^* - t^*$ rises). Non-exporters face tougher competition at home but experience no market expansion implying they reduce their product lines and do not change their process choice. Exporters experience a market expansion which induces them to engage in more process innovation. Small exporters supply mostly to the domestic market implying they benefit little from better market conditions abroad. They suffer a deterioration in overall market conditions and respond by cutting back on product lines. Large exporters sell mainly in the foreign market and experience an overall improvement in market conditions. Market expansion and improvement in overall market conditions implies that large exporters increase both product and process innovation. These findings are consistent with differences in product innovation among Canadian firms. For ease of reference, I summarize the results in Proposition 4 below.

Proposition 4. *With a bilateral or foreign tariff reduction, exporters increase process innovation. Large exporters increase product innovation while small exporters and non-exporters reduce product innovation. A home tariff reduction has the opposite effects.*

3.2. **Discussion.** Before proceeding to the empirics, I briefly discuss my results in the context of related work on multiproduct firms (e.g. Bernard, Redding, and Schott 2006, Mayer, Melitz, and Ottaviano 2009, etc.). This recent literature emphasizes cost considerations to explain two stylized facts: how product selection within firms increases observed productivity after trade and why firms supply different products at home and abroad. I address a different question: how trade affects product and process innovation.

The first point to note is that I allow firms to explicitly increase productivity through process innovation. Firms have direct control over productivity of products. The recent literature does not consider process innovation. It assumes within-firm cost heterogeneity and emphasizes selection of better products as the driving force for the observed rise in productivity. I abstract from within-firm heterogeneity and focus on process innovation. Though the focus is different, my model has implications for products and productivity of a firm.

As in Bernard, Redding, and Schott (2006) and Mayer, Melitz, and Ottaviano (2009), I find that productivities of exporters increase after a bilateral trade liberalization. In my model, productivity increases through process innovation due to higher scale from exports (and not from product selection). Consequently, productivity of non-exporters is not affected. I find that the effect of a bilateral trade liberalization on product innovation varies by export orientation. Bernard, Redding, and Schott and Mayer, Melitz, and Ottaviano find a negative relationship for all firms. My results are in line with Nocke and Yeaple (2005) where product responses differ by firm type. Nocke and Yeaple study the effects of trade liberalization on product choices of firms whose unit costs rise with their product range. They focus on diseconomies of scope from declining span of control in production. I focus on diseconomies through cannibalization of existing sales. Cannibalization is likely to be more important for firm decisions regarding introduction of new product lines within an industry while diseconomies of scope for introduction of products that span multiple industries. For instance, cannibalization will be more relevant when General Electric (GE) decides on the introduction of a new line of products within the consumer appliance industry while diseconomies of scope will be more important when it decides whether to enter a new line of business such as GE-Aviation. Consequently, this paper is complementary to Nocke and Yeaple. My model has a similar structure so it can be extended to incorporate diseconomies of scope in production.

4. Data Summary: Innovation and Trade policy in Thailand

This Section summarizes Thai manufacturing data used to examine the testable predictions of Section 3. Starting with an explanation of data sources, I outline measures for product and process innovation. Then I briefly discuss Thai trade policy changes during the period under study.

4.1. **Data.** I examine innovation among Thai manufacturers using establishment surveys from the 2004 and 2007 rounds of the Thailand Productivity and Investment Climate Surveys (PICS). The surveys were conducted by The Foundation for Thailand Productivity Institute (FTPI) with technical assistance from the World Bank (see The World Bank 2008 for details).

The 2007 round of the PICS covers 1,043 randomly sampled Thai manufacturing establishments spanning 34 ISIC 4-digit industries. Of these plants, 944 are incumbents that started operations before 2003. To examine within-firm product and process responses, I focus on incumbent establishments. Over 53 per cent of the incumbents exported in 2006 and 85 per cent reported making more than one type of product. Among incumbents surveyed in 2007, 426 were interviewed in the 2004 round.[10] These incumbents span 28 different ISIC 4-digit industries. About 60 per cent of these incumbents exported in 2006 and 88 per cent reported making more than one type of product.

The Thai PICS data contain detailed information on innovation responses, allowing for direct observation of key variables rather than indirect inference through other observables. This is particularly important for the question at hand as product and process innovation can have similar effects on commonly used variables (e.g. R&D expenditure, inferred firm productivity etc.). Product and process variables measure both invention and adoption. Adoption is likely to be important among smaller firms (especially in developing countries). It is not reflected in other measures such as patents.

The survey has its limitations. As is standard, most information is available at the establishment level and not at the firm level.[11] To address this issue, I use firm-level variables for the baseline results and supplement with establishment-level findings. A firm is defined as the "company that owns and operates" the surveyed establishment. Establishments can have more than one plant under their control. Over 86 per cent of the establishments have a single plant and 97 percent have

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[10]In personal communication, the FTPI clarified that most incumbents were not followed due to administrative changes in the survey following budget cuts.

[11]The stylized facts from the CUSFTA experience of Canadian manufacturers is at the establishment-level.

a single plant in a given industry. An establishment can be part of a larger firm that owns and operates more than one establishment. About 87 per cent of the establishments are not divisions of larger firms.

4.2. **Innovation Variables.** Innovation measures are constructed as follows. For the baseline results, I proxy for process innovation by percentage of machinery and equipment of a firm added in 2005-2006. Among incumbents, 32 per cent do not add any new machinery and equipment (M&E) while the remaining are process innovators with a positive percentage of new M&E. On average, new M&E is 71 per cent of the total market value of M&E in 2006.

As a robustness check, two other measures of process innovation are considered. Each establishment also reports the percentage of its M&E less than five years old and whether it "introduced new technology that has substantially changed the way the main product is produced" in 2005-2006. On average, 30 per cent of M&E is less than five years old and 46 per cent of incumbent establishments introduce a new process for their main product.

For the baseline results, I consider an indicator for product innovation based on data from both rounds of the PICS. A firm is a product innovator (coded as 1) if it increased its product range either by adding a new product and not dropping an old product or by opening a new plant and not closing an old plant. Plant openings and closings capture cases where firms make new products in new establishments and drop old products made in other establishments. However, plant openings and closings may pick up cases where firms simply shift an existing product to a new plant or close a plant making an existing product. This is less likely to be the case since plants within the same industry are mostly in geographically distinct locations, suggesting regional differentiation in product characteristics or marketing.[12] I consider plant openings and closings to account for this product differentiation. A potential problem is that locational choices need not entail any product differentiation and may be driven solely by transport cost considerations. To account for this, I exclude opening and closing of plants and find that the product innovation measure changes for only thirteen firms (that did not alter the product range of the establishment but opened a new plant). Key results are similar when plant openings and closings are considered to be distinct from changes in product range.

As many firms neither add nor drop products, I also consider a product innovation variable that categorizes firms into adding products, doing nothing and dropping products. As a robustness

[12] Less than two per cent of the establishments have plants belonging to the same industry in the same city or town.

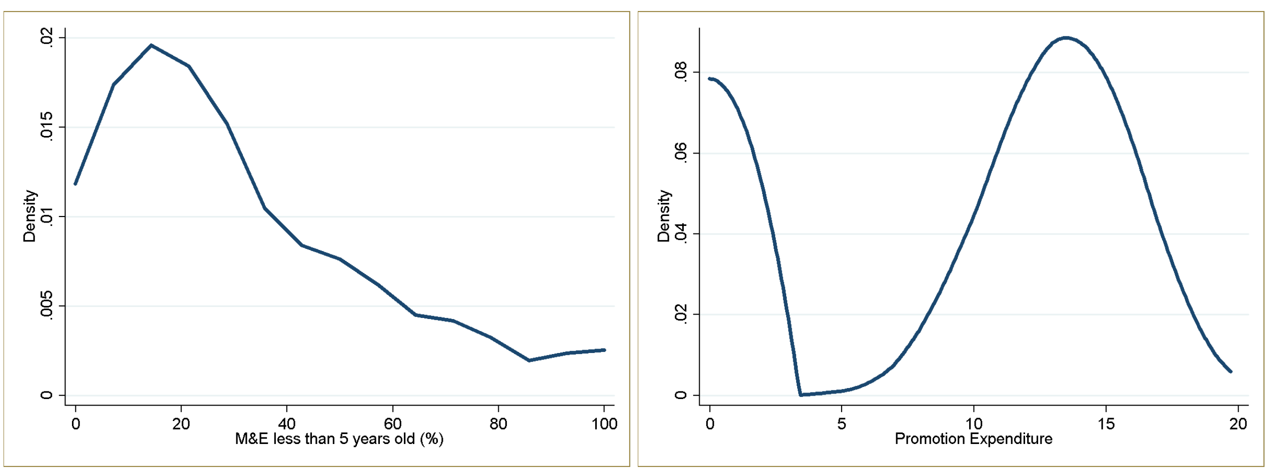
check, I proxy for product innovation by promotion expenditure of the firm in 2005-2006. The marketing literature shows that product introductions entail a rise in marketing expenses (e.g. Gielens and Steenkamp 2004, Quelch and Kenny 1994).

TABLE 1. Prevalence Rates for Product and Process Innovation

Percentage of Incumbents by Innovation Status			
Product & Process	Only Product	Only Process	None
28.1	7.5	43.5	20.9

Focusing on incumbent firms between 2002 to 2006, Table 1 provides a summary of process innovators (adding new M&E) and product innovators (adding new products or plants). Over a quarter of the incumbents engage in both product and process innovation. Figure 4.1 summarizes another set of measures for product and process R&D. Panel A shows the distribution of percentage of M&E less than five years old. Almost half the establishments have a quarter or less of new M&E. Panel B plots the distribution of promotion expenditure in 2005-2006. I add one to the promotion expenditure (in Thai Bahts) and take logs so the zero values correspond to zero promotion expenditure. About 35 per cent of incumbents spend nothing on promotion. Half the firms with positive promotion expenditure spend between 7 to 190 thousand USD on promotion in 2005-2006.

FIGURE 4.1. Distributions of New M&E and Promotion Expenditure



(A) M&E less than 5 years old in 2006

(B) Promotion Expenditure in 2005-2006

4.3. **Thai Trade Policy.** I examine innovation responses of Thai manufacturing firms to tariff changes between 2003 to 2005-2006. The share of manufacturing in Thailand's GDP increased from 34.8 per cent in 2003 to 35.1 per cent in 2006. The share in total merchandise exports rose from 74.8 per cent in 2003 to 76.6 per cent in 2005.

During this period, Thailand restructured its tariff regime. Tariffs are the main source of trade protection and the simple average of applied MFN tariffs for manufacturing declined from 11 per cent in 2003 to 8.7 per cent in 2006/07 (The WTO 2007). Home tariffs were lowered in over a third of the tariff lines.

I focus on applied tariff rates as they capture the extent to which tariffs change exporting costs in practice. An applied tariff rate is the actual tariff rate charged on a given import transaction. An applied tariff rate is lower than the bound tariff rate which is the maximum rate to which a country commits itself at the GATT/WTO. Over a quarter of all Thai tariff lines are not bound. Bound rates are considerably higher than applied tariff rates. Applied rates can be changed at any time (up to the bound rates) through executive notifications. During the period under study, the Thai government changed its applied tariff rates in most industries. These changes in applied rates were highly unpredictable implying they can be considered unanticipated policy changes from the perspective of firms (e.g. The WTO 2007, Sally and Street 2007).

Thailand also negotiated several bilateral trade agreements (e.g. with Australia, India, Bahrain). The bilateral agreements were limited in scope as measured by tariff lines or importance of trading partners (see Dhingra 2009). Consequently, unilateral Thai tariff changes constitute the primary trade policy change in this period.

Summary statistics for the percentage fall in effectively applied tariff rates of Thailand and its trading partners are given in Table 2 (see Appendix for details). In the PICS sample, establishments report the product code (ISIC 4-digit) for their main product only. Consequently, Table 2 summarizes tariff changes for ISIC 4-digit categories of the main product for Thai incumbents. Fall in tariffs refers to change in tariffs from 2003 to their average during 2005 and 2006.

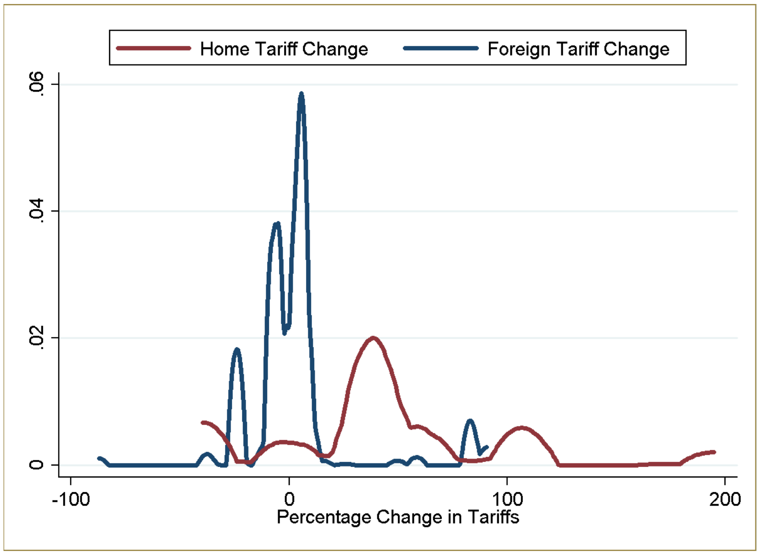
TABLE 2. Percentage Fall in Home and Foreign Tariffs

	Obs.	Mean	S.D.	Min	Max	Low
Home tariff change Δt	944	42.3	53	-40	195	5
Foreign tariff change Δt^*	944	2.6	25	-87	90	17

Notes: Low refers to number of industries with absolute tariff change lower than 10%.

As shown in Table 2, home tariffs vary much more than foreign tariffs. Standard deviation of home tariffs is two times that of foreign tariffs. Percentage fall in foreign tariffs ranges from -87 to 90 per cent. However, seventeen out of 28 industries experience a change in foreign tariffs of

FIGURE 4.2. Distributions of Percentage Changes in Home and Foreign Tariffs



less than ten per cent. I report these as Low tariff change industries in Table 2. Only five industries show low home tariff changes. A visual summary of tariff changes is provided in Figure 4.2 which plots the densities of home and foreign tariff changes. Six industries show a rise in Thai tariffs while the remaining have tariff cuts ranging from 2 to 194 per cent. Foreign tariff changes show a peak near zero while home tariff changes reflect sufficient cross-industry variation. Consequently, I focus on Thai tariff changes in the empirical section. Given the limited work on developing country firms, Thai tariff changes present an interesting case study to examine the relationship between trade and innovation.

5. EMPIRICS: IMPACT OF TRADE LIBERALIZATION ON PRODUCT AND PROCESS INNOVATION

This Section outlines an estimation strategy for testing the predicted impact of trade liberalization on product and process innovation. Proposition 4 states that home tariff cuts reduce the relative size of the home market, resulting in lower process innovation among exporters. A lower market size reduces competition at home, resulting in higher product innovation among small exporters and non-exporters but lower product innovation among large exporters. I test whether fall in market size from home tariff cuts has the innovation implications expected from Proposition 4.

5.1. **Process Innovation.** To examine the predicted relationship between Thai tariff changes and process innovation, I consider two different specifications. First, I test whether a home tariff reduction is negatively associated with process innovation of exporters. Second, I test whether home tariffs reduce economies of scale through lower exports per product, resulting in less process innovation.

Let $\Delta\omega$ denote process innovation and $E = 1$ indicate exporters in 2006. Fall in Thai tariffs is denoted by Δt. For the first method, the estimating equation is

$$\Delta\omega = \beta_1 \Delta t + \beta_2 \cdot E \cdot \Delta t + Z'_\omega \zeta_\omega + \epsilon_\omega \tag{5.1}$$

where Z_ω is a vector of controls. Parameters β_1 and β_2 allow the relationship between process innovation and tariff cuts to vary by export status. By Proposition 4, non-exporters ($E = 0$) do not change their process innovation in response to tariffs implying $\beta_1 = 0$. Exporters ($E = 1$) lower process innovation with a fall in home tariffs implying $\beta_2 < 0$.

I estimate Equation (5.1) and test for the expected signs of β_1 and β_2. Process innovation is proxied by percentage of new M&E expenditure of a firm in 2005-2006. As this is a truncated variable, Equation (5.1) is estimated as a tobit regression. I control for export status in 2006 and time-invariant industry effects in Equation (5.1). The baseline results are reported in Column (1) of Table 3.

TABLE 3. Estimation results: Process Innovation and Tariff Reductions

Firm's New M&E	Exp. Sign	(1) Coef. (S.E.)	Establishment's M&E less than 5 yrs old	Exp. Sign	(2) Coef. (S.E.)
Δt	$\beta_1 = 0$	-0.515	ΔExport per product	$\beta_\omega > 0$	0.410**
		(0.728)			(0.022)
Exporter$\cdot\Delta t$	$\beta_2 < 0$	-0.284*	Initial process		yes
		(0.139)	Industry dummies		yes
Exporter		1.126**	First-stage: ΔExport per product		
		(0.348)	Δt	$\beta_t < 0$	-0.874**
Industry dummies		yes			(0.236)
N		914	N		385
Log-likelihood		-1875.678	Log-likelihood		-1396.508

Notes: **and *denote 1 and 5 per cent significance levels.

As expected, Column (1) of Table 3 shows process innovation of non-exporters does not have a significant relationship with tariff reductions at home i.e. β_1 is not statistically different from zero. Process innovation of exporters is negatively associated with tariff reductions at home (i.e. $\beta_1 < 0$).

These baseline results provide support for the process innovation implication of Proposition 4. I proceed to examining whether a tariff-induced rise in exports per product is positively associated with process innovation. To test this relationship, I use information on change in exports per product (ΔE) of incumbent establishments between 2002 to 2006. Change in exports per product (ΔE) is a measure of percentage rise in average export sales per product from 2002 to 2006 (see Appendix for precise definition).[13] Instead of Equation (5.1), I estimate the following instrumental variable (IV) regression:

$$\Delta\omega = \beta_\omega \Delta E + Z_\omega' \zeta_\omega + \epsilon_\omega \qquad \Delta E = \beta_t \Delta t + Z_e' \zeta_e + \epsilon_e \tag{5.2}$$

where Z_ω and Z_e are controls including initial process characteristics and industry effects (as in Branstetter 2006 and Lileeva and Trefler 2007). Process innovation is proxied by percentage of establishment's M&E less than five years old. As this variable ranges from 0 to 100, Equation (5.2) is estimated as an IV-tobit regression. The RHS includes change in exports per product (ΔE) which is instrumented with home tariff reductions (Δt). As pointed out by Lileeva and Trefler (2007), this approach identifies process innovation from exporting for firms whose exports per product responded to tariff changes.

Column (2) of Table 3 summarizes key results and full details are provided in Column (2) of Table 5 in the Appendix. As expected, a home tariff reduction is negatively associated with exports per product ($\beta_t < 0$). Instrumenting with tariff reductions, I find higher exports per product are associated with more process innovation ($\beta_\omega > 0$) implying economies of scale is a driving force for investment in process R&D.

5.1.1. *Robustness.* In the Appendix, I examine robustness of key results for process innovation by considering different control and process variables.

Column (1) of Table 5 in the Appendix presents results for Equation (5.1) using different control variables. As Thai tariff liberalization encompassed import duty reductions on inputs, I control for fall in average import duty between 2002 and 2006 for each 4-digit ISIC industry. A fall in import duty on capital goods has the expected positive sign but is statistically insignificant. Controlling for supply-side considerations such as learning new technology from a client multinational corporation (MNC) or participating in MNC licensing/training/quality certification programs, firm characteristics such as percentage of foreign ownership and number of plants in the same industry does not affect key results. In fact, these variables are individually insignificant but this may be

[13]Quantities are not reported in PICS 2007. I use sales data and note that the comparative static predictions are similar for sales and quantities.

due to high correlation with other controls. Results are robust to commonly used proxies for firm characteristics such as initial firm size (measured by sales in 2001), R&D expenditure of the firm and current establishment size (measured by number of workers in 2006). Process innovation is positively associated with each of these characteristics.

Results for the IV specification of Equation (5.2) are similar when additional controls including other initial characteristics of the establishment in 2002-2003 are used.[14] In particular, the controls include productivity measures based on Ackerberg, Caves, and Frazer (2006) (see Appendix for estimation details), number of plants in the same industry, foreign ownership, indicators for MNC technology support through learning and other programs, import duty reductions and indicator for whether a loan was needed in 2003.

Finally, Column (2) of Table 6 reports results for a different process innovation measure that indicates whether the firm introduced a new production process for its main product. This is a binary dependent variable so I estimate Equation (5.1) as a probit regression. As expected, Thai tariff reductions are negatively associated with process innovation of exporters.

5.2. **Product Innovation.** According to Proposition 4, small exporters and non-exporters increase product innovation while large exporters reduce product innovation to ease intra-firm cannibalization after a home tariff reduction. To test this relationship, I consider branding status and adapt the reduced form estimation of Baldwin and Gu (2004) and Bernard, Redding, and Schott (2006) to account for the disparate impact of tariff changes across firms due to brand effects.

For the baseline results, product innovation (Δh) is an indicator for firms that increased their product range. I estimate a probit regression with Δh as the dependent variable. The RHS includes percentage change in Thai tariffs (Δt) and its interactions with branding and export orientation. Intra-firm cannibalization is expected to play a role for firms that differentiate their products through branding. I observe whether firms brand their products and define $B = 1$ if a firm has a brand and 0 otherwise. About 47 per cent of incumbents brand their products while the remaining 53 per cent have no brand.[15]

For firms with branded products, the predicted relationship between product innovation and tariff changes varies by export orientation. I interact tariff changes with a measure of export orientation to allow the slopes to vary by export orientation. This captures the stronger theoretical

[14] I omit these results for brevity. All unreported results are available upon request.

[15] For readers surprised by the richness of variables, Thailand has more to offer (such as the "exercise behavior survey" and the "sport played and sport watching behavior survey").

result that the relationship between home tariff cuts and product innovation is monotonic in export orientation. Interacting tariff reductions with export orientation also avoids sensitivity problems associated with cutoffs for large exporters.

Export orientation is measured by the share of exports in total sales of an establishment (ES). Here export orientation is defined in terms of share in total supply $q^x/(q+q^x) = \theta/(1+\theta)$ instead of $q^x/q = \theta$. This avoids the problem of dealing with zero domestic supply. The mean export share is 33 per cent of sales and sixty per cent of incumbents export in 2006. I include interactions of export orientation with tariff changes as RHS variables and estimate Equation (5.3) given below:

$$\Delta h = \beta_1 \Delta t + \beta_2 (ES \cdot \Delta t) + \beta_3 (B \cdot \Delta t) + \beta_4 (B \cdot ES \cdot \Delta t) + Z_h' \zeta_h + \epsilon_h \tag{5.3}$$

where Z_h is a vector of controls. I consider the relationship between product innovation and home tariff reductions (Δt) of firms with branded products relative to firms without branded products. Brand effects imply that small exporters and non-exporters respond to home tariff liberalization by increasing product innovation ($\beta_3 > 0$) while large exporters respond by reducing product innovation ($\beta_4 < 0$) to ease intra-firm cannibalization. I test whether $\beta_3 > 0$ and $\beta_4 < 0$ as implied by Proposition 4.

Column (1) of Table 4 presents baseline results for Equation (5.3). For firms with branded products, I find that lower home tariffs are positively associated with product innovation of non-exporters and small exporters (i.e. $\beta_3 > 0$) but negatively associated with product innovation of large exporters (i.e. $\beta_4 < 0$). Column (2) of Table 4 shows that the relationship holds even after controlling for branding, exporting and industry effects.

5.2.1. *Robustness.* In the Appendix, I consider different control and product variables to highlight the robustness of key results for product innovation.

Column (2) of Table 6 in the Appendix shows that results for Equation (5.3) are robust to using additional control variables such as foreign ownership, import duty changes etc. Details are provided in the Appendix and two noteworthy variables are discussed here. Firms participating in MNC licensing/training/quality certification programs are more likely to engage in product innovation. In line with Manova (2009), I find a higher probability of product innovation among less credit-constrained firms that reported not needing a loan in 2003.

Columns (1) and (2) of Table 7 report results for Equation (5.3) using different measures of product innovation. In Column (1), I consider all three product innovation categories (add, do nothing

TABLE 4. Estimation results: Product Innovation, Brands and Tariffs

Product Innovation	Exp. Sign	(1) Coef. (S.E.)	(2) Coef. (S.E.)
Fall in Thai tariff (Δt)		-0.267**	-0.110
		(0.102)	(0.239)
Export share$\cdot\Delta t$		0.511**	0.357**
		(0.046)	(0.131)
Brand$\cdot\Delta t$	$\beta_3 > 0$	**0.387****	0.184*
		(0.015)	(0.085)
Export share$\cdot$Brand$\cdot\Delta t$	$\beta_4 < 0$	**-0.266****	-0.189**
		(0.033)	(0.072)
Export share			0.137
			(0.091)
Brand			0.173**
			(0.065)
Intercept		-0.378**	
		(0.097)	
Industry dummies			yes
N		416	416
Log-likelihood		-267.420	-264.726

Notes: **and *denote 1 and 5 per cent significance levels.

and drop) and estimate an ordered probit regression. In Column (2), product innovation is proxied by promotion expenditure and Equation (5.3) is estimated as a tobit regression. Firms selling branded products continue to show a positive relationship between product innovation and Thai tariff reductions at low levels of export shares and a negative relationship at high levels of export shares.

5.3. **Discussion.** To assess the role of trade liberalization in innovation, I provide quantitative interpretations of the estimated effects on innovation. Tariff changes are quantitatively important in explaining variation in each type of innovation. From Table 3, a 1 per cent Thai tariff cut reduces process innovation (measured by new M&E as a percentage of market value) by 0.28 per cent and exports per product by 0.01 per cent. For product innovation, I focus on interpreting responses to the average Thai tariff cut. With the average reduction, a non-exporter with branded products has a 20 per cent higher probability of engaging in product innovation than a non-exporter without branded products. An exporter supplying only to the foreign market has an 11 per cent lower probability of engaging in product innovation if it makes branded products rather than unbranded products.

These results show that the theoretical relationship between tariff changes and innovation implied by Proposition 4 is empirically relevant. Home tariff cuts lower process innovation of exporters. Brand effects imply a negative relationship between Thai tariff reductions and product innovation for large exporters but a positive relationship for other firms. It is reassuring that the implied tariff and innovation relationship finds empirical support even though I focus only on incumbents (which reduces the contrast between exporters and non-exporters).

A remaining question is whether intra-firm cannibalization is at work in explaining these effects. The first piece of evidence is that branded and unbranded firms show different product innovation responses to trade liberalization. The second piece of evidence is that demand estimates for Thai manufacturing establishments indeed show a negative relationship between demand for a given product and its other products. I discuss this direct empirical evidence for intra-firm cannibalization briefly.

5.3.1. *Intra-firm Cannibalization.* In the Appendix, I estimate demand for the main product of an establishment as a function of its price, aggregate demand for all products in the industry and demand for other products of the establishment. Following Foster, Haltiwanger, and Syverson (2008), prices are instrumented with supply-side variables (firm-specific productivity). I use both observable productivity measures and unobservable productivity measures (TFPs from instrumental variables regression and Ackerberg, Caves, and Frazer 2006/Doraszelski and Jaumandreu 2007 productivities). I extend Foster et al. by considering demand for other products as a determinant of demand for the main product of an establishment. Demand for other products is instrumented with product R&D costs r_h. Considering different specifications, I find that demand for the main product of an establishment falls with a rise in demand for its other products. On average, a 1 percent rise in consumption of other products lowers demand for the main product by 0.1 percent. For multiproduct firms (selling more than one product), the average elasticity is 0.32. Intra-firm cannibalization is directly supported for Thai establishments in 2001-2002. This provides promising evidence in favor of the role of intra-firm demand linkages in firm decisions.

6. CONCLUSION

This paper provides a multiproduct linear demand model to study the impact of trade liberalization on product and process innovation. I introduce brand differentiation and show that intra-firm cannibalization distinguishes product and process innovation.

A firm's new product cannibalizes its old products more than products of other firms. Testing directly for demand linkages within Thai brands, I show that intra-firm cannibalization is an empirically important feature. When firms face intra-firm cannibalization, product innovation acts as an instrument to ease import competition. This has consequences for the effects of trade on product innovation.

Unlike product innovation, process innovation does not produce cannibalization effects. Instead, it lowers the cost of making a product and encourages its production. When firms enjoy economies of scale, process innovation and export opportunities reinforce each other. This has consequences for the effects of trade on process innovation.

Trade provides an opportunity to supply to a larger market. At the same time, trade makes competition fiercer and firms are faced with higher demand elasticities. Market expansion results in greater process innovation through economies of scale. On the other hand, tougher competition and adjustment of multiproduct firms to cannibalization results in lower product innovation.

At the individual level, large exporters get a sufficient boost in market size to outweigh the deterioration in product market conditions at home. Large exporters engage in greater product innovation at the expense of other firms. Process innovation remains unaffected among non-exporters but increases among exporters as they increase their production runs to supply to the foreign market.

In the empirical analysis, I confirm these responses for incumbent Thai firms between 2002-2006. Thai exporters experiencing a tariff-induced rise in scale engage in greater process innovation. Brand effects interact with export orientation to ensure incumbents have the predicted product innovation responses to Thai tariff changes.

Trade has conflicting effects on within-firm variety and productivity. This paper takes initial steps to unbundle the relationship between trade and innovation. I examine the role of intra-firm demand linkages in distinguishing product and process innovation. Moving beyond the standard channel of economies of scale, I show that trade affects innovation through the new channel of intra-firm cannibalization. This highlights how import competition affects innovation and explains why trade affects product and process innovation differently. However I do not address how firms adjust between trading equilibria. Future theoretical work and empirical studies based on longer panels can provide more insight into this issue.

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APPENDIX A. THEORETICAL & EMPIRICAL RESULTS

A.1. **CES and Logit Preferences: Invariance of Innovation to Trade Liberalization.** I introduce process innovation in the standard multiproduct Krugman-Melitz setting with nested CES preferences. In this setup, innovation is invariant to trade liberalization. A similar result holds with nested Logit preferences.

A.1.1. *Consumers.* Consider the same economic structure as in Section 2. The only difference is that the utility function has a nested CES form of Allanson and Montagna (2005).

$$U \equiv (\int q_j^{(\sigma-1)/\sigma} dj)^{\sigma/(\sigma-1)} \qquad q_j \equiv (\int q_{ji}^{(\varepsilon-1)/\varepsilon} di)^{\varepsilon/(\varepsilon-1)} \quad \varepsilon > \sigma > 1$$

Let $Q \equiv U$. Then the inverse demand for product i produced by firm j is

$$p_{ji} = IQ^{-\frac{\sigma-1}{\sigma}} q_j^{-\frac{\varepsilon-\sigma}{\varepsilon\sigma}} q_{ji}^{-1/\varepsilon}$$

The parameter σ captures the degree of across-firm substitutability while ε captures the degree of within-firm substitutability. Let $\gamma \equiv \varepsilon - \sigma$. Then γ captures the degree of cannibalization with $\gamma = 0$ implying no cannibalization. When $\gamma > 0$, there is intra-firm cannibalization.

A.1.2. *Firms.* I start with homogeneous firms. The process innovation FOC is similar to Section 2, $c'(\omega)(q + \tau q^x) = r_\omega$ where τ is an iceberg transport cost. Optimal price of a product supplied to the domestic and export markets are $p = \sigma c/(\sigma - 1)$ and $p^x = \sigma\tau c/(\sigma - 1)$ reflecting the usual CES property of constant markups.[16] Optimal product range h is given by

$$[p - c]q + [p^x - \tau c]q^x - r_\omega \omega - r_h + \underbrace{h\{q(\partial p/\partial q_j)(\partial q_j/\partial h) + q^x(\partial p^x/\partial q_j^x)(\partial q_j^x/\partial h)\}}_{\text{Cannib. Effect}} = 0 \tag{A.1}$$

With CES preferences, the rate of cannibalization from total firm quantity q_j is constant and given by $(\partial p/\partial q_j)q_j/p_{ji} = -\gamma/\varepsilon\sigma$. The reader may verify that product innovation h directly affects profits through cannibalization (since $\partial h/\partial\gamma \neq 0$) while process innovation does not.

A.1.3. *Product and Process Innovation with Trade Liberalization.* CES preferences imply constant markups and a constant cannibalization rate γ. This results in the following quantity per product $q + \tau q^x$:

$$\frac{1}{\varepsilon - 1}[c(\omega)(q + \tau q^x)] - r_\omega \omega = r_h \tag{A.2}$$

First, note that firm scale $q + \tau q^x$ and hence process innovation does not depend on intra-firm cannibalization γ. Second, Equation (A.2) fixes scale and process innovation implying they are invariant to trade liberalization.

In a Krugman economy (with symmetric firms), free entry implies $h = f(\varepsilon - \gamma - 1)/\gamma c(q + 1_x \tau q^x)$. Unlike process innovation, product innovation cannibalizes directly and indirectly as $dh/d\gamma < 0$. As with process innovation, product innovation is also unaffected by trade liberalization. For completeness, I note that in a Melitz economy with fixed exporting costs $f_x > 0$ and heterogeneous firms, exporters increase their product range after trade liberalization but process innovation continues to be unresponsive as shown earlier. These results are summarized in a Proposition below.

Proposition. *In a Krugman-Melitz economy, trade liberalization has no impact on process innovation. In the absence of fixed exporting costs, trade liberalization has no impact on product innovation either.*

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[16] I assume a firm can anticipate the effect of its decisions on its own products. Allanson and Montagna (2005) and Agur (2007) implicitly assume that a firm prices each of its products separately, implying $p = \varepsilon c/(\varepsilon - 1)$. I note that my result regarding insensitivity of innovation choices is valid even when this pricing strategy is considered.

This result is similar to Atkeson and Burstein (2007) for process innovation in single-product firms. Atkeson and Burstein do not consider product innovation but find process innovation is invariant to trade liberalization for single product firms in the absence of fixed exporting costs.

The reader may verify that innovation is invariant to trade liberalization when the standard multiproduct nested Logit demand of Anderson, De Palma, and Thisse (1992) is considered instead (see pp. 250). The reason is similar: markups and the rate of cannibalization are exogenously fixed by taste for diversity in products and brands. This is not surprising given the close relationship between the logit and CES framework (see Verboven 1996 for an equivalence relationship).

A.2. **Multiproduct Linear Demand Model.**

Assumption 1. *$\delta > (L+L^*)c^2 \max\{2, 1+r_h/r_\omega\}/4r_\omega$ and $\alpha > c + 2(\gamma f/L)^{1/2}, 2\eta^{1/2}$.*

The first condition ensures firms produce positive quantities for the home market. The second condition ensures consumption of both homogeneous and differentiated goods in equilibrium, as in Melitz and Ottaviano (2005).

Lemma. *Under Assumption 1, all firms produce the same product range for the home and foreign markets i.e, $h = h^x$.*

Let h be the common product range sold to both markets, h^d be the product range sold only to the home market and h^o be the product range sold only to the export market. I examine whether an interior solution with positive h^d or h^o constitutes an equilibrium. The first case with both $h^d, h^o > 0$ is immediate. A firm can re-organize part of its production (with an inferior process) to the product range with a better process. This will save on duplication of r_h costs and will weakly increase profits due to better technology. For the remaining two cases with only one of h^d or h^o greater than zero, I sketch the proofs below. Note that the proof does not require symmetry of Home and Foreign (L^* need not equal L).

Claim 1. If $h^d, q^x > 0$ then process for products sold to both markets is better than process for products sold only to the domestic market ($\omega > \omega^d$).

Proof. Suppose $h^d > 0$ and a firm starts to export some $h^o \leq h^d$ of this product range to the foreign market. For brevity, let n denote $\omega^{1/2}$. Then the net gain in profits is

$$\Delta\Pi = h^o(p^o - (1-n^d)c - t^*)q^o - \frac{\gamma}{L^*}h^o q^o h q^x = h^o q^o[\{\frac{2\delta}{L^*}q^x - (n-n^d)c\} - \frac{\delta + \gamma h^o}{L^*}q^o]$$

If $n \leq n^d$ then the term in curly brackets is positive, implying h^o and q^o can be set to yield a positive gain. Thus, for $h^d > 0$ to be an equilibrium, it must be the case that $n > n^d$ so that exporting from the h^d range does not increase profits further. A similar argument applies for $h_o > 0$. □

Claim 2. If $q, q^x > 0, h^d = h^o = 0$.

Proof. I show that a non-trivial solution (with $q, q_x > 0$ and $h_d > 0$) is not an equilibrium. From the FOCs for q and q^d, we find that $(\delta/L)(q - q^d) = c(n - n^d)/2$. This yields the following relationships:

$$(q + q^x) = \frac{\delta}{L}(q - q^d)/(c^2/4r_\omega) + q^d \qquad q^x = \left(\frac{\delta}{L} - \frac{c^2}{4r_\omega}\right)(q - q^d)/(c^2/4r_\omega) \tag{A.3}$$

From the FOCs for h and h^d, we know that $\delta(q^2/L + (q^x)^2/L^*) - (c^2/4r_\omega)(q + q^x)^2 = r_h$ and $[\delta/L - (c^2/4r_\omega)](q^d)^2 = r_h$. Adding and subtracting $\delta(q_d^2 - 2qq_d)/L$ on the LHS of each equation, we get

$$\frac{\delta}{LL^*}(q - q^d)^2\left(\frac{\delta}{L} - \frac{c^2}{4r_\omega}\right)\left(\delta - (L + L^*)c^2/2r_\omega\right)(c^2/4r_\omega)^{-2} = 0$$

Consequently $q = q^d$ which gives us $q^x = 0$ from Equation (A.3). Thus $h^d > 0$ cannot be an equilibrium. A similar argument applies for $h^o > 0$. $\square$

Proposition. *Starting from $t = t^*$, a fall in foreign tariffs t^* and a rise in home tariffs t increase the size of the home economy.*

Proof. Equilibrium outcomes of the home country with trade are given by equilibrium outcomes of the home country in autarky when its market size is set at sL (instead of L). The size factor is $s = (1+\theta)^2/(1+\theta^2)$ and I show that s is negatively related to t^* but positively related to t.[17]

For this, I first determine θ. From the FOCs for q and q^x, $\theta = [a^* - t^* - c(\omega)]/[a - c(\omega)]$. Let $y \equiv q + q^x$ be the total quantity per product. Then industry-wide demand conditions are given by:

$$\text{(A.4)} \qquad a = c + 2y\left[\left(\frac{\delta+\gamma h}{L}\right)\frac{1}{1+\theta} - \frac{c^2}{4r_\omega}\right] \quad a^* = c + t^* + 2y\left[\left(\frac{\delta+\gamma h}{L}\right)\frac{\theta}{1+\theta} - \frac{c^2}{4r_\omega}\right]$$

and the analogous expressions for the foreign firms. Along with the FOCs, Equation A.4 provide six equations in six unknowns a, a^*, θ, θ^*, y, y^*, h and h^*. I show that $d\theta/dt^* < 0$ and $d\theta^*/dt^* > 0$ for any pair of non-prohibitive tariffs $t = t^* > 0$.

The ZPC condition gives $y^2 = r_h/[\delta/sL - c^2/4r_\omega]$ and the FE condition gives $h^2 = sLf/\gamma y^2$. This implies the following comparative statics:

$$\frac{1}{y}\frac{dy}{dt^*} = \frac{1}{2s}\frac{\delta/sL}{(\delta/sL) - (c^2/4r_\omega)}\frac{ds}{dt^*} \quad \frac{1}{h}\frac{dh}{dt^*} = -\frac{1}{y}\frac{dy}{dt^*} + \frac{1}{2s}\frac{ds}{dt^*}$$

Totally differentiating industry-wide demand conditions (Equation A.4), I substitute for the above expressions and solve for $d\theta/dt^*$ and $d\theta^*/dt^*$. Evaluating at $t = t^* > 0$ yields a symmetric solution with $\theta \in [0, 1)$ and

$$\frac{d\theta}{dt^*} = -\frac{D_x + B}{(D_x+B)^2 - (D-B)^2}\frac{1}{2y} \quad \frac{d\theta^*}{dt^*} = \frac{D-B}{D_x+B}\frac{d\theta}{dt^*}$$

where $B \equiv (\delta + \gamma h)/L(1+\theta)^2$ and

$$D \equiv \left[\frac{\delta/L(1+\theta) - c^2/4r_\omega}{\delta/sL - c^2/4r_\omega}\frac{\delta}{sL} + \frac{\gamma h}{L}\frac{1}{1+\theta}\right]\frac{1-\theta}{(1+\theta)(1+\theta^2)}$$

$$D_x \equiv \left[\frac{\theta\delta/L(1+\theta) - c^2/4r_\omega}{\delta/sL - c^2/4r_\omega}\frac{\delta}{sL} + \frac{\gamma h}{L}\frac{\theta}{1+\theta}\right]\frac{1-\theta}{(1+\theta)(1+\theta^2)}$$

It may be shown that $D - B < 0$, $D_x + B > 0$ (so that $D_x + B - (D - B) > 0$) and $D_x + D > 0$ implying $d\theta/dt^* < 0$ and $d\theta^*/dt^* > 0$. We have now established that $d\theta/dt^* < 0$ and $d\theta^*/dt^* > 0$. A direct corollary is that a bilateral trade liberalization yields $d\theta/dt = -(1+\theta)^2[2(\delta+\gamma h)/L - \frac{(1-\theta)^2}{1+\theta^2}\{\delta/L\frac{\delta/sL}{\delta/sL - c^2/4r_\omega} + \gamma h/L]^{-1}/2 < 0$. Differentiating Equation A.4, the reader may verify that $da/dt^* = 2y(D-B)(d\theta/dt^*) > 0$ and $da^*/dt^* = 2y^*(D^* - B^*)(d\theta^*/dt^*) < 0$.

$\square$

A.3. **Heterogeneous Firms.** With firm heterogeneity, firm choices are determined in a manner similar to Section 2. The only difference arises from process innovation being a discrete choice. For brevity, firm's exporting and process choice is denoted by (x, ω). Then a firm adopting strategy $(x, \omega) = (0, 1)$ chooses not to export but chooses to engage in process innovation and earns profit $\Pi_{01}(c)$. A firm that is indifferent between strategies (x, ω) and (x', ω') is denoted by $c_{x\omega,x'\omega'}$. For instance, a firm with initial cost $c_{00,01}$ is indifferent between strategies $(0, 0)$ and $(0, 1)$. With this notation in hand, I provide a brief summary of firm decisions. I consider the interesting case where $c - \omega(c) \geq 0$ (so that producing differentiated goods entails real resources) and $\Pi_{1\omega}(0) \geq \Pi_{0\omega}(0)$(so that the most productive firm can export profitably).

[17]See Dhingra and Morrow (2008) for scaling properties of the linear demand model.

Domestic Supply Cutoff. A firm that does not adopt a new technology decides to stay in the home market if $\Pi_{00}(c) \geq 0$ where the subscript 00 denotes no exporting and no process innovation respectively. The lowest productivity firm that is indifferent between producing without process innovation and exiting is denoted by c_{00} so that $\Pi_{00}(c_{00}) = 0$. A 00 firm stays if $c \leq c_{00} = a - 2(\delta/L)^{1/2} r_h^{1/2}$. Similarly, a 01 firm stays if $c - \omega(c) \leq c_{00} - F$ where $F \equiv 2(\delta/L)^{1/2} r_h^{1/2}[(1 + r_\omega/r_h)^{1/2} - 1]$.

Domestic and Export Quantity. For brevity, let total quantity per product for a firm supplying to both domestic (d) and export (x) markets be $y \equiv q^d + q^x$. It is useful to summarize the ratio of exports to domestic sales of a product as $\theta \equiv q^x/q^d$. An exporting firm supplies $q^d = y/(1+\theta)$ to the domestic market and $q^x = \theta y/(1+\theta)$ to the foreign market. Optimal quantity is given by $y_{x\omega}(c) = (r_h + 1_{\omega>0} r_\omega)^{1/2}/(\delta/s_{x\omega}(c)L)^{1/2}$ where $s_{x\omega}(c)$ is the rise in scale for firm c when it engages in international trade.

As in the symmetric case, trade acts like an increase in market size. However, with heterogeneous firms, the scale factor varies with productivity. It is given by $s_{x\omega}(c) \equiv (1 + \theta_{x\omega}^2(c))/(1 + \theta_{x\omega}(c))^2$ and depends on the export to domestic quantity ratio $\theta_{x\omega}(c) = [a^* - t^* - c + 1_{\omega>0}\omega(c)]/[a - c + 1_{\omega>0}\omega(c)]$. Exporters supply a positive quantity to the foreign market implying a positive export ratio and a rise in scale ($s_{x\omega}(c) > 1$ for $x = 1$). Non-exporters do not supply to the foreign market so $\theta_{x\omega}(c) = 0$ implying the scale factor is exactly 1.

Export Cutoff. A firm exports if $\theta_{x\omega}(c) > 0$ implying the export cutoff is determined by $a^* - t^* - c_{x\omega} + 1_{\omega>0}\omega(c_{x\omega}) = 0$. Firms choosing ω export if their cost draws are lower than $c_{x\omega}$.

Having determined firm decisions, I first discuss the role of cannibalization in distinguishing product and process innovation. Then I discuss the impact of trade liberalization on each type of innovation.

Lemma 1. *Process innovation is unaffected by intra-firm cannibalization γ while product innovation falls as intra-firm cannibalization γ rises.*

Proof. The direct effects of cannibalization are similar to the symmetric firm case. I proceed to the indirect effects. From free entry,

$$-\sum_i \sum_j \int \Pi_i(c) g(c) dc/\gamma + \frac{da}{d\gamma} \sum_i \sum_j \int \frac{(hy)_i}{1+\theta_i} + \frac{da^*}{d\gamma} \sum_i \sum_j \int \frac{\theta_i (hy)_i}{1+\theta_i} = 0$$

The first term on the LHS is zero (by free entry). Consequently, the above equation simplifies to $A da/d\gamma + B da^*/d\gamma = 0$. Together with its foreign analog, $[(A^2 - B^2)/A] da/d\gamma = 0$. This yields $da/d\gamma = da^*/d\gamma = 0$ implying $d\theta/d\gamma = 0$. Differentiating $c_{10,11}$, we get $d\Pi_{11}/d\gamma = -\Pi_{11}/\gamma + [-1 + \omega'(c)](hy)_{11} dc_{10,11}/d\gamma$ and similarly for $d\pi_{10}/d\gamma$. At $c_{10,11}$, $\Pi_{10}(c_{10,11}) = \Pi_{11}(c_{10,11})$ so we are left with $[(-1 + \omega'(c))(hy)_{11} + (hy)_{10}] dc_{10,11}/d\gamma = 0$. Similarly, differentiating the other cutoffs, we get $dc_{10,11}/d\gamma = dc_{01,11}/d\gamma = dc_{00,11}/d\gamma = dc_{00,01}/d\gamma = 0$. Thus γ has no effect on process innovation. Using these relationships and the profit function, we find $dh/d\gamma = -2/\gamma < 0$. ☐

A.3.1. *Trade Liberalization.* Following Nocke and Yeaple (2005), I focus on characterizing firm responses in a given interior equilibrium and consider small changes with respect to t and t^* evaluated at $t = t^*$.

Lemma. *A fall in t^* or a rise in t lowers a and increases a^*.*

Proof. I focus on t^* here. The proof for t is similar. Let the lowest productivity firm that is indifferent between producing (with any strategy) and exiting be $\bar{c}$ so that $\Pi(\bar{c}) = 0$. In equilibrium, firms make zero profits implying

$$\int_0^{\bar{c}} \Pi(c) g(c) dc = \int_0^{\bar{c}} \max_{x\omega} \Pi_{x\omega}(c) g(c) dc = \sum_{x\omega} \sum_j \int_{\underline{c}_{x\omega,j}}^{\bar{c}_{x\omega,j}} \Pi_{x\omega}(c) g(c) dc = f$$

where $j \in J_{x\omega}$ denotes a segment of c over which strategy $x\omega$ is chosen. I allow for strategy $x\omega$ to be chosen over disconnected sets of c and only restrict the set of producers to be convex. Without loss of generality, I assume that $j = m_{x\omega}$ represents the highest cost segment of c draws over which strategy $x\omega$ is chosen and so on starting at 1.

Differentiating the free entry condition with respect to the foreign tariff faced by home exporters (t^*),

$$\sum_{x\omega}\sum_{j}[\Pi_{x\omega}(\bar{c}_{x\omega,j})g(\bar{c}_{x\omega,j})\partial\bar{c}_{x\omega,j}/\partial t^* - \Pi_{x\omega}(\underline{c}_{x\omega,j})g(\underline{c}_{x\omega,j})\partial\underline{c}_{x\omega,j}/\partial t^* + \int_{\underline{c}_{x\omega,j}}^{\bar{c}_{x\omega,j}} \partial\Pi_{x\omega}(c)g(c)/\partial t^* dc] = 0$$

I assume there are no "holes" and producers comprise a connected set in c. The cutoff point where a firm is indifferent between strategy i and k is given by $\Pi_i(\bar{c}_{ij}) = \Pi_k(\bar{c}_{ij})$. For firms in the neighborhood of $\bar{c}_{ij}$ with lower cost draws, the cutoff $\bar{c}_{ij}$ also represents the lower cutoff for strategy k implying $\Pi_k(\bar{c}_{ij}) = \Pi_k(\underline{c}_{kj'})$. Thus all intermediate cutoffs drop out from the above equation. Moreover, $c_{i,1} = 0$ irrespective of i since production is always viable for a firm with cost draw 0. Finally, a cutoff firm $\bar{c}_{i,m_i}$ is indifferent between staying and exiting implying $\Pi_i(\bar{c}_{i,m_i}) = 0$ irrespective of i. We are left with the following condition:

$$\sum_{i}\sum_{j}\int_{\underline{c}_{i,j}}^{\bar{c}_{i,j}} \partial\Pi_i(c)g(c)/\partial t^* dc = 0 \tag{A.5}$$

Differentiating the profit functions with respect to t^*, we find that

$$\Pi_{00}'(t^*) = (hy)_{00} da/dt^* \qquad \Pi_{10}'(t^*) = (hy)_{10}[da/dt^* + \theta_{10}(da^*/dt^* - 1)]/(1+\theta_{10})$$
$$\Pi_{01}'(t^*) = (hy)_{01} da/dt^* \qquad \Pi_{11}'(t^*) = (hy)_{11}[da/dt^* + \theta_{11}(da^*/dt^* - 1)]/(1+\theta_{11})$$

I substitute for these expressions in Equation A.5 and its foreign counterpart to solve for changes in aggregate market conditions da/dt^* and da^*/dt^*. For brevity, let $A_i \equiv (hy)_i/(1+\theta_i)$ and $B_i \equiv \theta_i A_i$. Let the aggregated A_i and B_i terms be $A \equiv \sum_i \sum_j \int_{\underline{c}_{ij}}^{\bar{c}_{ij}} A_i(c)g(c)dc$ and $B \equiv \sum_i \sum_j \int_{\underline{c}_{ij}}^{\bar{c}_{ij}} B_i(c)g(c)dc$ respectively. Then the differentiated free entry condition gives

$$A da/dt^* + B da^*/dt^* - B = 0$$
$$A^* da^*/dt^* + B^* da/dt^* = 0$$

Starting at $t = t^*$ implies $A = A^*$ and $B = B^*$ so $da^*/dt^* = -(B/A)(da/dt^*)$. Note that B/A is the ratio of export production to domestic production. Thus B/A represents the average θ in economy ($\tilde{\theta} \equiv B/A$). Substituting in the first equation, we can solve for changes in aggregate home and foreign market conditions as $da/dt^* = AB/(A^2 - B^2) > 0$ and $da^*/dt^* = -B^2/(A^2 - B^2) < 0$. Thus changes in profits are given by

$$\Pi_{00}'(t^*) = (hy)_{00}\frac{\tilde{\theta}}{1-\tilde{\theta}^2} \qquad \Pi_{10}'(t^*) = (hy)_{10}\frac{1}{1-\tilde{\theta}^2}\frac{\tilde{\theta}-\theta_{10}(c)}{1+\theta_{10}(c)}$$
$$\Pi_{01}'(t^*) = (hy)_{01}\frac{\tilde{\theta}}{1-\tilde{\theta}^2} \qquad \Pi_{11}'(t^*) = (hy)_{11}\frac{1}{1-\tilde{\theta}^2}\frac{\tilde{\theta}-\theta_{11}(c)}{1+\theta_{11}(c)}$$

□

Lemma. *A bilateral reduction in tariffs lowers a.*

Proof. As earlier, the home free entry condition can be differentiated to determine the changes in market conditions. The change in market conditions is given by $da/dt = B/(A+B) = \tilde{\theta}/(1+\tilde{\theta}) >$

0. Thus changes in profits under each strategy are given by

$$\Pi_{00}'(t^*) = (hy)_{00}\frac{\tilde{\theta}}{1-\tilde{\theta}} \qquad \Pi_{10}'(t^*) = (hy)_{10}\frac{1}{1+\tilde{\theta}}\frac{\tilde{\theta}-\theta_{10}(c)}{1+\theta_{10}(c)}$$

$$\Pi_{01}'(t^*) = (hy)_{01}\frac{\tilde{\theta}}{1-\tilde{\theta}} \qquad \Pi_{11}'(t^*) = (hy)_{11}\frac{1}{1+\tilde{\theta}}\frac{\tilde{\theta}-\theta_{11}(c)}{1+\theta_{11}(c)}$$

□

Proposition. *4 With a fall in t^*, a rise in t or a bilateral reduction in tariffs, in the home country:*
Process innovation increases among exporters but remains unaffected among non-exporters.
Non-exporters lower product innovation. Exporters lower product innovation when their export share falls short of the average export share ($\theta < \tilde{\theta}$) and increase product innovation when their export share exceeds the average export share ($\theta > \tilde{\theta}$).

Proof. If a firm was a non-exporter prior to the tariff change and continues to stay a non-exporter, then it faces a choice between strategy 00 and 01. The cutoff for technology upgrading of non-exporters is determined by the cutoff $c_{00,01}$ defined as $\Pi_{00}(c_{00,01}) = \Pi_{01}(c_{00,01})$ which implies $\omega(c_{00,01}) = F$. This cutoff is not affected by a tariff change as $\omega'(c_{00,01})dc_{00,01}/dt^* = 0$. Firms that remain non-exporters do not change process innovation.

Firms that previously exported and continue to export face a choice between 10 and 11. Let $c_{10,11}$ denote the cutoff firm that is indifferent between $\Pi_{11}(c_{10,11}) = \Pi_{10}(c_{10,11})$. Then $[s_{10}^{1/2} - s_{11}^{1/2}(1 - \omega'(c_{10,11}))]dc_{10,11}/dt^* = [1/(1+\theta_{10}^2)^{1/2} - 1/(1+\theta_{11}^2)^{1/2}]da/dt^* + [\theta_{10}/(1+\theta_{10}^2)^{1/2} - \theta_{11}/(1+\theta_{11}^2)^{1/2}][-1+da^*/dt^*] > 0$ implying $dc_{10,11}/dt^* < 0$ for $\omega'(c) < 0$ and $dc_{10,11}/dt^* > 0$ for $\omega'(c) > 1$. More firms that continue to export undertake process innovation (as strategy 11 instead of 10 is adopted).

Firms that switch export status are those that move from 00 to 10 or 11 and from 01 to 10 or 11 and vice-versa. With a fall in t^*, if $c_{00,10}$ exists then it rises. These 00 firms switch to 10 and there is no change in process innovation among these new exporters. If $c_{00,11}$ exists then we need to consider the tradeoff between 00 and 11 strategies. A 00 firm switches to 11 when $\Pi_{00} > \Pi_{11}$. The change in the cutoff is given by $[s_{11}^{1/2}(1-\omega'(c_{00,11})) - 1]dc_{00,11}/dt^* = [1/(1+\theta_{11}^2)^{1/2} - 1]da/dt^* + [\theta_{11}/(1+\theta_{11}^2)^{1/2}][-1+da^*/dt^*] < 0$ implying $dc_{00,11}/dt^* < 0$ for $\omega'(c) < 0$ and $dc_{00,11}/dt^* > 0$ for $\omega'(c) > 1$. With a fall in t^*, 00 firms switch to 11 and process innovation increases among new exporters. The reader may verify that 01 firms never switch to 10 and vice-versa. Putting these results together, we can say that process innovation weakly increases among new exporters. The argument for bilateral liberalization is similar except $da^*/dt = da/dt$. Additionally, a rise in t^*, a fall in t or a bilateral increase in tariffs lowers process innovation among exporters but leaves process innovation unaffected among non-exporters. The argument is similar but now some 11 firms may switch to 00 or 10 implying process innovation falls among exporters.

A non-exporter reduces product innovation with a fall in t^* since $dh_i/dt^* = (L/2\gamma)da/dt^* > 0$ for $i = 00, 01$. Product innovation response of exporters depends on productivity. In particular, $dh_i/dt^* = (h_i/2\Pi_i)d\Pi_i/dt^*$ for $i = 10, 11$ so $\text{sgn}dh_i/dt^* = \text{sgn}d\Pi_i/dt^* = \text{sgn}(\tilde{\theta} - \theta_i(c))$. □

A.4. **Empirical Results and Variable Definitions.** For innovation estimation, tariff data for Thailand and its trading partners are taken from UNCTAD TRAINS available through the WITS utility. The value for t^* is a weighted average of tariffs of all trading partners, with average export shares during 1999-2006 serving as weights. The weights are kept constant in both years to avoid bias arising from change in trade structure in response to tariff changes. Fall in import duty refers to fall in average import duty paid on the most recent purchase of imported M&E by establishments in each 4-digit ISIC industry between 2002 and 2006.

In the process innovation estimation of Equation (5.2), exports per product is average export sales of the top three products of a firm. Let r_k^x denote revenue from export of product $k \in \{1, 2, 3\}$.

Then $E = (r_1^x + r_2^x + r_3^x)/3$. I scale the average exports by 10^{-7}. Change in exports per product (ΔE) refers to changes from 2002 to 2006. I define ΔExports per product (ΔE) as $E_1/(1+E_0)$ where the scaling is applied to account for zero exports in period 0. Sector-specific producer price indices from the Bureau of Trade and Economic Indices of Thailand are used to convert all values into 2002 Bahts. For the product innovation estimation, I am unable to categorize ten of the 426 incumbents. Since this is only 2 per cent of the sample, the selection bias is likely to be small.

Estimation results for the innovation equations are given in Tables 5, 6 and 7. All RHS variables refer to 2006 unless otherwise noted. The results are qualitatively similar when additional controls (such as those in Column 1 of Table 5) are included on the RHS.

TABLE 5. Estimation results: Process Innovation, Exports and Tariffs

Firm's New M&E	Exp. Sign	(1) Coef. (S.E.)	Establishment's M&E less than 5 years old	Exp. Sign	(2) Coef. (S.E.)
Δt	$\beta_1 = 0$	-0.632	ΔExports per product	$\beta_\omega > 0$	0.410**
	$\beta_2 < 0$	(0.407)			(0.022)
Exporter$\cdot\Delta t$		-0.217*	New Process in 2002-3		-0.399**
		(0.101)			(0.115)
Exporter		0.671**	New M&E in 2002-3 (bn Bt)		-0.250
		(0.017)			(0.219)
R&D expenditure (mn Bt)		0.083**	Remaining years of M&E 2003		0.004
		(0.006)			(0.004)
Employment ('000)		0.189**	Computer controlled M&E 2003		0.006**
		(0.024)			(0.001)
Sales in 2001 (10 bn Bt)		0.340**	Plant in same industry 2003		-0.025
		(0.012)			(0.141)
Foreign ownership		-0.001	Industry dummies		yes
		(0.005)			
Plants in same industry		0.066	First-stage Estimates:		
		(0.065)	Dependent Variable: Δ Exports per product		
Import duty fall 2002-2006		0.266			
		(0.256)	Fall in Thai tariff	$\beta_t < 0$	-0.874**
Learn tech from MNC		-0.059			(0.236)
		(0.357)			
Tech program of MNC		0.059	Controls from Process Eq.		yes
		(0.167)			
Industry dummies		yes	Industry dummies		yes
N		857	N		385
Log-likelihood		-1598.822	Log-likelihood		-1396.508

Notes: Standard errors in parentheses, $^{\dagger}p < .10$, $^{*}p < .05$, $^{**}p < .01$

A.5. **Intra-firm Cannibalization: Empirics.** Sections 2 and 3 assume consumers have a taste for diversity in brands which induces intra-firm cannibalization. I directly test for intra-firm cannibalization among Thai manufacturers in 2001-2002. Starting with a description of the empirical method and key variables, I report results for cannibalization.

A.5.1. *Empirical Method.* To test for cannibalization, I estimate the multiproduct demand function of Equation (2.2) and examine intra-firm demand linkages. The demand function is

$$q_{ji} = (L/\delta)\alpha - (L/\delta)p_{ji} - (\gamma/\delta)q_{j,k\neq i} - (\eta/\delta)Q \equiv \alpha' + \delta' p_{ji} + \gamma' q_{j,k\neq i} + \eta' Q \tag{A.6}$$

TABLE 6. Robustness: Product and Process Innovation

Product innovation indicator		(1) Coef.	(S.E.)	New process		(2) Coef.	(S.E.)
Fall in Thai tariff (Δt)		-0.042	(0.063)	Δt	$\beta_1 = 0$	0.027	(0.130)
Export share$\cdot\Delta t$		0.372**	(0.080)	Exporter$\cdot\Delta t$	$\beta_2 < 0$	-0.248**	(0.041)
Brand$\cdot\Delta t$	$\beta_3 > 0$	0.168**	(0.016)	Exporter		0.288**	(0.060)
Export sh$\cdot$Brand$\cdot\Delta t$	$\beta_4 > 0$	-0.185*	(0.078)	Employment ('000)		0.345	(0.479)
Export share		0.173*	(0.076)	Sales 2001 (10bn Bt)		2.808**	(0.883)
Brand		0.190**	(0.003)	R&D (mn Bt)		0.012	(0.013)
Plants in same ind. 2003		0.026	(0.172)	Plants in same ind.		0.011	(0.055)
Foreign ownership in 2003		0.001	(0.001)	Foreign ownership		0.000†	(0.000)
Learn tech from MNC 2003		-0.545	(0.393)	Learn tech from MNC		0.448**	(0.005)
Tech prog. of MNC 2003		0.329*	(0.140)	Tech prog. of MNC		0.057	(0.071)
Import duty fall 2002-2006		0.060	(0.069)			0.057**	(0.020)
Promotion 2003		0.011	(0.009)				
Did not need loan in 2003		0.020**	(0.004)				
Industry dummies		yes				yes	
N		399				884	
Log-likelihood		-249.779				-560.15	

Notes: Standard errors in parentheses, $^{\dagger}p < .10$, $^{*}p < .05$, $^{**}p < .01$

TABLE 7. Robustness: Product Innovation, Brands and Tariffs

Product Innovation	Exp. Sign	(1) Coef.	(S.E.)	(2) Coef.	(S.E.)
Fall in Thai tariff (Δt)		-1.978**	(0.570)	-0.224	(0.217)
Export share$\cdot\Delta t$		-3.429**	(0.222)	0.307**	(0.102)
Brand$\cdot\Delta t$	$\beta_3 > 0$	4.086**	(0.307)	0.292**	(0.068)
Export share$\cdot$Brand$\cdot\Delta t$	$\beta_4 < 0$	-1.526**	(0.416)	-0.157*	(0.073)
Export share		7.214**	(0.809)	0.166**	(0.023)
Brand		2.385**	(0.179)	0.044	(0.050)
Industry dummies		yes			
N		944		416	
Log-likelihood		-2513.239		-429.741	

Notes: Standard errors in parentheses, $^{\dagger}p < .10$, $^{*}p < .05$, $^{**}p < .01$

From Equation (A.6), own price effect is $\partial q_{ji}/\partial p_{ji} = \delta'$. Demand effect of other products of the firm is $\partial q_{ji}/\partial q_{j,k\neq i} = \gamma'$. The model assumes demand for product i of firm j is negatively related to its own price and to quantities of other products of firm j (i.e. $\delta', \gamma' < 0$). To assess the validity of these assumptions, I estimate slopes δ' and γ' and test whether $\delta' < 0$ and $\gamma' < 0$.

A straightforward approach is to estimate Equation (A.6) to obtain slope coefficients for prices p_{ji} and other quantities $q_{j,k\neq i}$. Focusing on single-product firms, Foster, Haltiwanger, and Syverson (2008) estimate Equation (A.6) without the multiproduct term ($q_{j,k\neq i}$ on the RHS). To get consistent estimates of the price coefficient (δ'), they instrument prices with supply side variables that proxy for unit costs c (such as firm-specific total factor productivity measures).

I follow a similar method but modify their approach in two ways. First, I allow for intra-firm demand linkages through quantities of other products of a firm ($q_{j,k\neq i}$ on the RHS) and directly test for intra-firm cannibalization by estimating γ'. To get consistent estimates for intra-firm cannibalization, I use supply-side variables that proxy for firms' product development costs r_h as instruments. Second, I do not estimate Equation (A.6) in levels and modify the variables to account for data limitations. Working with levels is problematic in the absence of detailed information on quality of products. I use first differences of quantities and prices to overcome time-invariant differences in quality. To compare quantities (q_{ji} with q_j and Q), I normalize the variables by quantity. Details are discussed in the next sub-section.[18]

Let $\Delta z \equiv z_t - z_{t-1}$ denote the change in z between periods t and $t-1$. Then the estimating equation is as follows:

$$\frac{\Delta q_{ji}}{q_{jit}} = \delta' \frac{\Delta p_{ji}}{q_{jit}} + \gamma' \frac{\Delta q_{j,k\neq i}}{q_{jit}} + \eta' \frac{\Delta Q}{q_{jit}} + Z'_{ji}\zeta + \epsilon_{jit} \tag{A.7}$$

where Z_{ji} is a vector of controls. With Equation (A.7), own price effect is $\Delta q_{ji}/\Delta p_{ji} = \delta'$ while other products' effect on demand is $\Delta q_{ji}/\Delta q_j = \gamma'$. To directly examine the assumptions of Sections 2 and 3, I estimate Equation (A.7) with c and r_h proxies as instruments and test whether $\delta', \gamma' < 0$. When $\delta', \gamma' < 0$, consumers show a taste for diversity in products and brands. Taste for diversity in brands implies firms must adopt strategies to lower intra-firm cannibalization of their market shares.

A.5.2. *Data and Variables.* Data on Thai establishments is taken from PICS 2004. Revenue and quantity data for the main product are only available in the 2004 round. Over 1,300 establishments were randomly sampled across 35 ISIC 4-digit industries in 2004. About 450 establishments sold at least two products in 2002. A similar survey has been used by Kee and Krishna (2008) which confirms the soundness of the data. I have conducted various checks and find that the variables used are of satisfactory quality.

For Demand Equation (A.7), key variables are quantity q_{ji}, price p_{ji}, quantities of other products $q_{j,k\neq i}$ and industry-wide quantity Q. Quantity q_{ji} and price p_{ji} refer to the main product for the domestic market. The data contains revenue and physical quantity of the main product for each year. Following Foster, Haltiwanger, and Syverson (2008), I construct unit prices as the ratio between revenue and quantity. Quantity of other products of the plant $q_{j,k\neq 1}$ refers to quantities of the top two products (other than the main product).[19] It is proxied by the sum of these two products in terms of product 1 units, i.e. $q_{j,k\neq 1} = q_{j2}(p_{j2}/p_{j1}) + q_{j3}(p_{j3}/p_{j1})$. Aggregate quantity Q is deflated Thai domestic absorption for the ISIC 2-digit industry. This is the finest level of disaggregation at which gross output data is available prior to 2002. Domestic absorption is the sum of gross output and imports net of exports.[20] Gross value of output is from the Thai Industrial Surveys (2000 and 2002), import values are from the UNCTAD TRAINS (2000 and 2001) and exports are computed from average export ratios of PICS firms in 2001 and 2002. The choice of years and datasets reflects availability of data. I deflate the value of domestic absorption by price p_{jit} to obtain quantity equivalents (Q). The variable used in the demand estimation is $\Delta Q/q_{jit} = (Q_t - Q_{t-1}L_{t-1}/L_t)/q_{jit}$ where L is GDP. Time periods $t-1$ and t are 2001 and 2002 respectively.

A.5.3. *Measurement differences.* As mentioned earlier, normalizing by q_{ji} takes account of measurement differences for other products of the firm and industry. The variable construction implies $\Delta q_{j,k\neq i}/q_{jit}$ is expenditure on other products relative to expenditure on the main product of an establishment. Similarly, $\Delta Q/q_{jit}$ is expenditure on all products of the industry relative to expenditure on the main product of an establishment. This takes care of comparability issues arising

[18]Foster, Haltiwanger, and Syverson (2008) minimize concerns of quality and measurement differences by restricting their sample to less differentiated goods. In recent work, Demidova, Kee, and Krishna (2006), Katayama, Lu, and Tybout (2009), De Loecker (2007) and Aw, Roberts, and Xu (2008) also estimate demand parameters with plant-level data. Considering single-product firms, Demidova, Kee, and Krishna regress quantity on price, instrumenting prices with estimated firm-specific productivities, capital and age. In the absence of quantity data, the other three papers provide methods to infer demand parameters from revenue data.

[19]Similar results hold when total domestic revenue of the firm is used instead. For brevity, I do not report these results.

[20]Exchange rates for import data are from the International Financial Statistics (IFS) official average exchange rate series.

from different measurement units across products in Equation (A.7). For the moment, I treat a 5-ounce cup and a 10-ounce cup of yogurt as distinct products differentiated by their packaging. In this case, differences in units of measurement is a form of product differentiation that will be reflected in the demand parameters. For the baseline results, I adopt this view and examine the relationship between demand for the main product and other products of an establishment. An alternative approach is to compare price of a 5-ounce cup of yogurt with a 10-ounce cup in terms of price per ounce (rather than price per cup). I adopt this view to check the robustness of the relationship.

A.5.4. *Results.* I start with results for the baseline demand estimation using observable proxies for firm productivity. Next I account for unobservable differences in productivity. Finally I discuss robustness with respect to different specification, instruments and controls.

Baseline Results. For the baseline results, observable proxies are used as instruments for price p_{ji} and quantities of other products $q_{j,k\neq i}$. I employ the wealth of plant-level information to proxy for unit costs c and product development costs r_h. The set of instruments (I) consists of input characteristics (price of main raw material, whether raw material was supplied to plant's unique specifications, total wages of directors/officers and production workers), finance variables (whether the plant needed a loan, percentage of retained earnings in working capital and in net investments), R&D expenditure and productivity measures.

PICS 2004 contains very detailed information on firm characteristics related to productivity. For the moment, I use these observable characteristics to proxy for productivity. Later I will estimate a production function to address unobservable differences in productivity. The observable productivity proxies consist of technology variables (indicators for new and upgraded technology, percentage of machinery less than five years old), skill variables (indicators for employee training or participation at a Skills Development Institute) and ownership variables (percentage of government or foreign ownership).

Column (1) in Table 8 provides baseline results using I and observable proxies for firm productivity as instruments. Two-step GMM estimates for Equation (A.7) are reported. Demand parameters have the expected signs. Own price is negatively related to demand as $\delta' = -0.008$. An increase of 1 Baht in own price reduces demand for the main product by 0.008 units. The slope of quantities of other products has the expected negative sign as $\gamma' = -0.23$. Demand for the main product falls by 0.23 units when consumption of firm's other products rises by a single unit. This implies intra-firm cannibalization is empirically relevant.

Quantitatively, intra-firm cannibalization can be interpreted as follows. On average, a 1 percent rise in consumption of other products lowers demand for the main product by 0.1 percent (i.e. average elasticity with respect to other products is 0.1). For multiproduct firms (selling more than one product), the average elasticity is 0.32 and the median elasticity is 0.18. Thus intra-firm cannibalization is an important feature of the data.

Industry-level quantity has the expected negative sign with $\eta' = -0.001$. A unit increase in aggregate quantity Q lowers demand for the main product by 0.001 units. I control for time-invariant sector differences through 4-digit ISIC fixed effects. Quality changes are captured by an indicator for whether the firm "significantly upgraded an existing product line" in 2002-3. A significant upgrade in product quality increases demand for the main product.

Unobservable Productivity. The observable proxies for productivity are very rich. However, a voluminous literature highlights the importance of unobserved productivity differences across firms. To account for these unobservable differences, I consider two productivity measures based on the literature on production function estimation. As is well-known, standard techniques to measure productivity perform poorly due to various problems (e.g. endogeneity bias). I use both the instrumental variables and the control function approach to address these problems.

TABLE 8. Multiproduct Demand Estimates

Quantity of main product	Exp. Sign	**(1) Coef.** (Std. Err.)	**(2) Coef.** (Std. Err.)	**(3) Coef.** (Std. Err.)
Price of main product	$\delta' < 0$	-0.008**	-0.010**	-0.008**
		(0.0001)	(0.0001)	(0.000)
Quantity of other products	$\gamma' < 0$	-0.227**	-0.26**	-0.088**
		(0.007)	(0.008)	(0.004)
Quantity of all firms' products	$\eta' < 0$	-0.001**	-0.001**	-0.0006**
		(0.0001)	(0.0001)	(0.000)
Quality upgrade indicator		1.449**	1**	1.473**
		(0.1)	(0.071)	(0.03)
4-digit ISIC Fixed Effects		yes	yes	yes
N		1026	927	895
R^2		0.78	0.7	0.88
First Stage Instruments: Input, Finance, R&D and Observable Productivity				
Estimated Productivity		No	TFP-IV	ACF-LP/R&D

**denotes 1 per cent significance level.

The first measure for productivity builds on the instrumental variables approach. I replace observable technology variables used earlier with total factor productivities (TFPs). TFPs are obtained as residuals from a Cobb-Douglass production function expressed in logs as $y = \beta_0 + \beta_l l + \beta_k k$. The LHS ($y$) is value added (i.e. sales net of material and energy costs) deflated by price of the plant's main product. The RHS variables are value of labor and replacement value of capital which are instrumented with average wage, depreciation and firm-specific long-term domestic interest rate.

The second measure builds on control function methods of Ackerberg, Caves, and Frazer (2006) and Levinsohn and Petrin (2003) which explicitly allow productivities to vary over time. I do not use the estimation technique of Olley and Pakes (1996) since forty percent of the sample consists of firms with zero investment. As in the TFP regression, the LHS is deflated value added and the RHS consists of value of labor and capital. The control function to proxy for productivity is a third degree polynomial in materials and energy expenditure and lagged value of R&D expenditure. As suggested by Doraszelski and Jaumandreu (2007), the R&D term is an additional control which embodies both exogenous shocks and endogenous investment to raise productivity.

I report production function estimates for the instrumental variables (TFP-IV) and control function (ACF-LP/R&D) methods in Columns (1) and (2) of Table 9 respectively. In each case, labor and capital coefficients are reasonable. Consequently, I use both measures to check the robustness of subsequent results.

Demand equation results using annual TFP-IV and ACF-LP/R&D productivity instruments are reported in Columns (2) and (3) of Table 8 respectively. The key qualitative results are similar to the baseline results. Demand parameters continue to have the expected signs and show that intra-firm cannibalization negatively affects demand for a product.

Robustness. To account for differences in units of measurement, I follow FHS and take logarithmic values as the relevant unit of observation of variables. Taking logs and first-differencing the demand function takes account of differences in measurement units across firms. I estimate the following demand function where all variables are specified in natural logarithms (as in FHS).

$$\Delta q_{ji} = \delta' \Delta p_{ji} + \gamma' \Delta q_{j,k\neq i} + \eta' \Delta Q + \epsilon_{ji} \tag{A.8}$$

TABLE 9. Production Function Estimation

Value added deflated by firm price	**(1) TFP-IV Coef.** (Std. Err.)	**(2) ACF-LP/R&D Coef.** (Std. Err.)
Labor	0.440**	0.441†
	(0.167)	(0.26)
Capital	0.563**	0.486*
	(0.190)	(0.246)
4-digit ISIC FE	yes	
N	2537	2546
R^2	0.23	

Notes: **, *and †denote 1, 5 and 10 per cent significance levels.
Bootstrapped standard errors are reported in Column (2).

Following Demidova, Kee, and Krishna (2006), ΔQ is a fixed effect for the 4-digit ISIC industry. Table 10 shows that quantities have a negative relationship with own price and other products of the establishment implying intra-firm cannibalization is empirically valid. Results for Equation (A.8) using only observable productivity and unobservable productivities (TFP-IV and ACF-LP/R&D in 2001) as instruments are given in Columns 1, 2 and 3 of Table 10.

TABLE 10. Multiproduct Demand Estimates

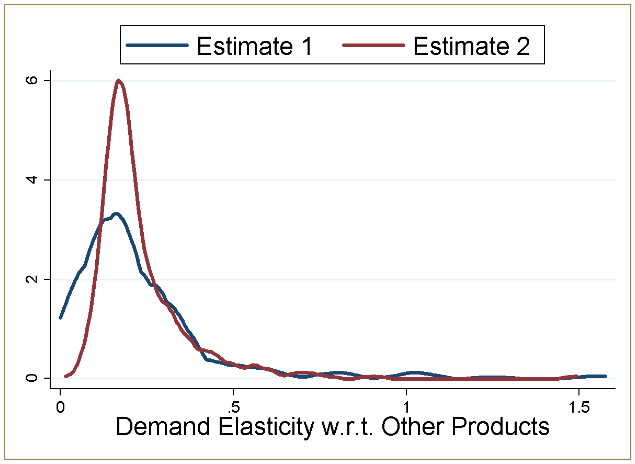
Quantity of main product	Exp. Sign	**(1) Coef.** (Std. Err.)	**(2) Coef.** (Std. Err.)	**(3) Coef.** (Std. Err.)
Price of main product	$\delta' < 0$	-0.842**	-0.835**	-0.774**
		(0.099)	(0.063)	(0.07)
Quantity of other products	$\gamma' < 0$	-0.276**	-0.309**	-0.297**
		(0.052)	(0.039)	(0.05)
4-digit ISIC Fixed Effects		yes	yes	yes
N		1029	954	898
R^2		0.26	0.25	0.26
First Stage Instruments: Input, R&D and Observable Productivity				
Estimated Productivity		No	TFP-IV	ACF-LP/R&D

**denotes 1 per cent significance level.

Taking log-levels as the unit of observation, I interpret demand elasticity with respect to other products as $\gamma' q_{j,k\neq 1}/q_{j1}$. (All quantities are scaled up by 1000 to avoid negative log values). Based on Column (1) of Table 10, average elasticity with respect to other products is 0.08. For multiproduct establishments (selling more than one product), the average elasticity is 0.23 and the median elasticity is 0.19. These estimates are close to those from Column (1) of Table 8. Distributions of estimated demand elasticities with respect to other products from the first and second estimating equations (Equations A.7 and A.8) are plotted in Figure A.1.

Results are not sensitive to additional controls (omitted for brevity). Indicators for multiplant firms and multiplant firms with another plant in the same industry do not alter the key findings. These indicators have the expected negative signs but are usually not statistically significant. In the absence of detailed product characteristics, I include quality measures such as year of introduction of the product to the domestic market, indicators for ISO-certification, enforcement of quality standards by buyers, warranty or uniqueness of the product. Controlling for these quality variables as exogenous or endogenous variables yields qualitatively similar results.

FIGURE A.1. Distribution of Estimated Perceived Cross-Elasticity of Demand



Overall, intra-firm cannibalization finds strong support among Thai establishments during 2001-2002. This confirms the key assumption of the multiproduct linear demand model and implies that firms engage in steps to induce brand loyalty.