TRADING AWAY WIDE BRANDS FOR CHEAP BRANDS

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ABSTRACT. Firms face competing needs to expand product variety and reduce production costs. Trade policy affects firm investments in product variety and production processes differently. Access to larger markets enables innovation to reduce costs. Although firm scale increases, foreign competition reduces markups. Firms react by narrowing their product varieties to recapture these lost markups. I provide a theory detailing this conflicting impact of trade policy and address welfare gains from trade. Accounting for firm heterogeneity, I show support for the theoretical predictions with firm-level innovation data from Thailand's manufacturing sector which experienced unilateral home tariff changes during 2003-2006.

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1. INTRODUCTION

Trade liberalization provides welfare gains by increasing product variety and productivity within industries. Krugman (1980) and Melitz (2003) show how trade provides these gains through entry and exit of firms. Empirical studies confirm the importance of this channel of entry and exit. At the same time, these studies point to the contribution of a second channel: innovation responses within firms. Firms make investments to expand their product variety and lower their production costs. Their innovation activities make up a large fraction of aggregate changes in industry-level variety and productivity.[1] This paper examines how trade policy affects firm investments in product variety and cost reduction.

New plant-level studies find trade liberalization has opposite effects on firm investments in product variety and cost reduction.[2] Standard models explain how trade liberalization induces cost reduction within firms. Trade expands market size and enables firms to exploit economies of scale in process innovation. With a better production process, firms can produce a higher quantity (or better "quality") at the original production cost. However in such models, innovation occurs only along the process dimension as product variety is exogenously fixed within firms. Consequently, standard models do not include a tradeoff between product and process innovation of firms, and so cannot address how trade liberalization might impact this tradeoff. More specifically, these models cannot speak to the question why trade liberalization produces conflicting effects across product and process innovation. Nor can they answer the question of whether the choice between product and process innovation really matters.

The answers to these questions must hinge on how product and process choices differ from each other. If the net returns to these choices are qualitatively similar, then looking at aggregate innovation will suffice for many questions of interest. This is because product and process innovation will have similar implications and trade liberalization will not affect these choices differently. However, differences in product and process innovation are important in shaping relevant market outcomes such as product life cycles, firm growth, industry evolution and export participation.[3] At the same time, as observed above, changes in market conditions (such as trade liberalization) do not affect product and process innovation uniformly. This raises the question of distinct welfare effects as firms pursue different innovation strategies. I unbundle innovation to examine the tradeoff between product and process innovation.

To address this tradeoff, I focus on demand side effects of introducing more products and better processes. This provides an explanation for why product and process innovation differ and why

[1]For example, Bernard et al. (2010) find that within-firm product expansion accounts for about half of US output of new products. Doraszelski and Jaumandreu (2007) show within-firm productivity growth accounts for two-thirds of total productivity gains among Spanish firms.

[2]For example, Canadian firms cut back on their product lines and adopted more cost-reducing technologies as a result of the Canada-US Free Trade Agreement (Baldwin and Gu 2004, 2005).

[3]For example, Abernathy and Utterback (1978), Klepper (1996) and Becker and Egger (2007) document these effects.

trade affects them differently. To formalize these distinctions, I model brand differentiation in a monopolistic competition setting. Firms make multiple products within a brand and consumers consider products to be more substitutable within brands than across brands.[4] For example, when Yoplait introduces a new yogurt, demand for its original yogurt falls more than demand for an original Dannon yogurt. This intra-brand cannibalization induces a natural distinction between the returns to product and process innovation. When a firm widens its product variety, market shares of its existing products are cannibalized as consumers substitute into the firm's new products. This lowers the returns to product innovation. In contrast, upgrading the production process of a product reduces its unit cost without cannibalizing existing market shares. Process innovation therefore reflects economies of scale in the usual way; as quantity of a product rises, investments in its production process can be amortized more profitably.

These two channels of economies of scale and cannibalization together explain the varying effects of trade on innovation. Moving from autarky to free trade increases market size and raises the returns to process innovation through economies of scale. At the same time, opening to trade introduces import competition from foreign brands and lowers the residual demand for each domestic brand. Facing intra-brand cannibalization, each firm recognizes that it can cope with external competition from imports by cutting back on internal competition within its own brand. As a consequence, trade induces the typical firm to lower product innovation (through cannibalization) but increase process innovation (through economies of scale).

These firm responses have conflicting implications for welfare gains from trade. Process innovation raises productivity and increases welfare through lower prices. The drop in product innovation lowers welfare from domestic variety. This welfare loss is overcome by access to foreign brands which increases total variety. In the presence of brand differentiation, welfare from variety rises for another reason. Expansion in brands (at the expense of products within a brand) gives consumers access to more differentiated products. Thus, 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 trade liberalization. Bilateral liberalization increases the market size available to home firms. A bigger market increases the returns to process innovation due to economies of scale. At the same time, it lowers the returns to product innovation due to tougher competition from higher entry of firms. Therefore, home firms engage in more process innovation but less product innovation. On the other hand, a unilateral home tariff reduction has the opposite effects. A home tariff cut increases the market size available to foreign firms at the expense of market size available to home firms. A smaller market implies lower economies of scale so home firms lower their process innovation. However, a smaller market also has less competition so surviving home firms are able to increase their product innovation.

[4]Empirical evidence for higher substitutability within brands is provided by Broda and Weinstein (2010) using supermarket data and Hui (2004) using personal computers data. Also see Hui for a summary of supporting business and consumer psychology theories.

These results show how a typical firm chooses product and process innovation in response to bilateral and unilateral trade policies. To obtain richer testable predictions, I study the responses of firms with different levels of initial productivity. Under firm heterogeneity, the impact of trade policy on market expansion and competition is similar to that with homogeneous firms. But now each firm has a different share of the domestic and export markets so innovation responses vary across firms. As earlier, a home tariff reduction de-locates home firms and shifts market size towards foreign firms. Home exporters suffer a drop in exports as they lose market size to new and expanding foreign firms. They engage in lower process innovation. Non-exporters continue to sell only at home so they are shielded from a loss in scale through exports. In fact, surviving non-exporters and small exporters that sell mainly at home face lower competition due to de-location. They are able to increase product innovation at the expense of large exporters that sell mainly in the bigger foreign market.

I test these firm-level predictions for Thailand's manufacturing sector which experienced unilateral home tariff changes between 2003 and 2006. During this period, the Thai government unilaterally changed its tariffs, resulting in an average absolute change of 42 per cent in manufacturing tariffs. Home tariffs were increased in a few industries but most industries experienced a fall in home tariffs. I exploit the variation in Thai trade policy across industries to examine how tariff changes affected innovation responses of incumbent Thai firms.

Innovation is measured by direct survey questions on whether firms expanded their product variety or introduced new technologies. This minimizes the problem of strong empirical restrictions in distinguishing product and process innovation. Consistent with the theory, I find Thai tariff cuts lower process innovation of exporters, relative to non-exporters. Process innovation falls for firms experiencing a decline in exports per product. For product innovation, I focus on firms making branded products because they are most likely to face intra-brand cannibalization. As expected, I find non-exporters and small exporters increase product innovation while large exporters reduce product innovation with a fall in Thai tariffs. Therefore, the empirical application supports the predicted relationship between trade liberalization and innovation. As validity checks, I provide direct support for intra-brand cannibalization in Thailand and for corresponding innovation patterns of Malaysian firms.

The main contribution of this paper is to systematically examine how trade affects different dimensions of innovation. In contrast to the classic work of Grossman and Helpman (1991), I show that product and process innovation have varying implications for both positive and normative questions such as differences in firm responses and welfare impact of trade policy.[5] Aggregate innovation conceals these qualitative differences. I integrate insights from the innovation and multiproduct firm literature to address these differences. The innovation literature underlines how

[5]Grossman and Helpman consider quality and variety at the *industry*-level. They find that both quality and variety yield similar positive results but different normative results.

trade liberalization affects aggregate innovation through economies of scale (Grossman and Helpman 1993). Yeaple (2005), Bustos (2009) and Lileeva and Trefler (2010) show higher scale from exports is positively associated with better technologies. The important findings of Bustos and Lileeva and Trefler provide evidence for this positive relationship among Argentinean and Canadian firms. Unlike these papers, I consider both scale economies and demand linkages to study the tradeoff between technology and product variety.

To model product innovation, I build on recent work on multiproduct firms in international trade. Eckel and Neary (2010), Feenstra and Ma (2007) and Ju (2003) study cannibalization arising from strategic inter-firm competition among oligopolistic firms. I consider intra-brand competition which is a complementary feature as it can co-exist with strategic inter-firm competition in oligopolistic industries.[6] Within the monopolistic competition setting, Arkolakis and Muendler (2007), Bernard et al. (2005, 2006) and Mayer et al. (2009) study the role of cost linkages within multiproduct firms. They propose that expanding the product range entails higher production or market penetration costs, leading to differences in products sold across markets.[7] I abstract from differences in products across markets as my main purpose is to address product and process innovation. Instead, I focus on demand linkages within firms and show how they drive a wedge between the returns to product and process innovation.

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 summarizes innovation and trade policy in the Thai context. I test the implied relationship for Thai firms and discuss key empirical concerns. Section 5 concludes.

2. Theoretical Model

This Section provides a model of multiproduct firms that invest in their product variety and production processes. The model yields two main results. First, returns to product and process innovation differ substantively through intra-brand cannibalization. Second, opening to trade has opposite effects on product and process innovation.

To model these distinctions, I propose a linear demand structure with brand differentiation. The standard approach to model brand differentiation is through nested CES preferences where the first nest is defined over brands and the second nest over multiple products within each brand.[8] I depart from the standard CES assumption because it has very special implications for the relation between

[6]Unlike oligopolistic models with fixed number of firms, I study monopolistically competitive firms with free entry. I show that entry and exit of firms play a crucial role in determining innovation and welfare in my model.

[7]Eckel and Neary (2010) and Nocke and Yeaple (2005) propose rising production costs as well. Bernard et al. (2006, 2005) also consider the role of differences in product attributes in determining entry and exit of products.

[8]Allanson and Montagna (2005) use a nested CES demand structure to examine product variety within firms. The production side of this economy is similar to Krugman (1980) so it can be readily extended to study the impact of trade on product and process innovation.

trade and innovation. In an online Appendix, I show that nested CES preferences distinguish product and process innovation through cannibalization. However, they do not explain the differential effects of trade on innovation. With nested CES demand, I show that trade liberalization has no effect on either dimension of innovation in Krugman (1980) and on process innovation in Melitz (2003).

As is well-known, CES preferences are special in inducing all adjustments through the extensive margin of product variety. Product market competition and the rate of cannibalization are exogenously fixed so the returns to innovation are not altered through this channel. Consequently, I depart from CES preferences and provide a linear demand model with brand differentiation. In this setting, product market competition and the rate of cannibalization vary with trade liberalization, leading to differential effects of trade on innovation. I start with an exposition of the closed economy and then study the effects of trade liberalization.

2.1. **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. They pay an entry cost f to enter and produce a brand of goods. Firms can produce multiple products within a brand. I explain the role of brands in the following subsection and then consider its implications for product and process 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 strictly positive. As in Melitz and Ottaviano (2008), 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. Unlike Melitz and Ottaviano, 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.

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

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

where $q_j \equiv Lq^k_j$ 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 $i' \neq i$ of the same brand j is $\varepsilon_{ji,ji'} \equiv -(dq_{ji}/dq_{ji'})(q_{ji'}/q_{ji}) = (\gamma + \eta)(q_{ji'}/\delta q_{ji})$. Across-brand cross elasticity of brand j's product i with respect to any product i' of any other brand $j' \neq j$ is $\varepsilon_{ji,j'i'} \equiv -(dq_{ji}/dq_{j'i'})(q_{j'i'}/q_{ji}) = \eta(q_{j'i'}/\delta q_{ji})$.

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 than across brands.[9] This brand differentiation is embodied in a positive γ. When $\gamma > 0$, within-brand cross elasticity exceeds across-brand cross elasticity ($\varepsilon_{ji,ji'} > \varepsilon_{ji,j'i'}$). 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-brand cannibalization.

2.2. **Firms.** Having explained brand differentiation, I examine its implications for product and process innovation. I start with firm decisions in the simplest case of symmetric firms in autarky and then discuss the effects of trade.

In the differentiated goods industry, firms enter freely by paying a cost f. After paying entry costs, they can make products within a brand 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 unit cost c or choose a lower unit cost $c(\omega_{ji})$ by investing in process ω_{ji}. I assume $c(\omega_{ji}) \equiv c - c\omega_{ji}^{1/2}$ for $\omega_{ji} \in [0,1]$. Higher levels of ω_{ji} correspond to lower levels of unit cost ($c'(\omega_{ji}) < 0$) with $c(0) = c$ denoting no process innovation and $c''(\omega_{ji}) > 0$.[10] 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 an inverse demand $p_{ji} = (\alpha - \eta Q/L) - \delta q_{ji}/L - \gamma q_j/L \equiv a - \delta q_{ji}/L - \gamma q_j/L$.

[9]Using supermarket barcode data, Broda and Weinstein (2010) show the median intra-brand elasticity is thirty per cent higher than inter-brand elasticity. For similar theories and empirics, see Aaker (1991), Boush and Loken (1991) and Boush (1993) in marketing; Anderson et al. (1992) in industrial organization; Hui (2004) in management.

[10]The specific functional form for $c(\omega)$ is not crucial. Results are similar as long as the firm problem is concave. Sufficient conditions for an interior equilibrium are in the Appendix. A detailed proof is available in an online Appendix.

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 to amortize its entry costs. It chooses a product range of h_j products by investing in product R&D at a rate r_h per product. [11]

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.

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

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. 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.[12] Consequently, the firm problem can be re-written as $\Pi = h\{[p - c(\omega)]q - r_\omega \omega - r_h\} - f \equiv h\pi - f$ where π is profit per product. 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 cannibalization (when $\gamma = 0$). Later I show that process innovation does not cannibalize even after accounting for equilibrium quantity.

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 is $p = a - \delta q/L - \gamma hq/L$. Quantity q lowers consumers' willingness to pay through its own effect ($\delta q/L$) and its brand-wide effect ($\gamma hq/L$). The FOC for quantity supplied to the domestic market is

$$\frac{\partial \pi}{\partial q} = \underbrace{[p - (\delta + \gamma h)q/L]}_{\text{MR}} - \underbrace{c(\omega)}_{\text{MC}} = 0 \tag{2.3}$$

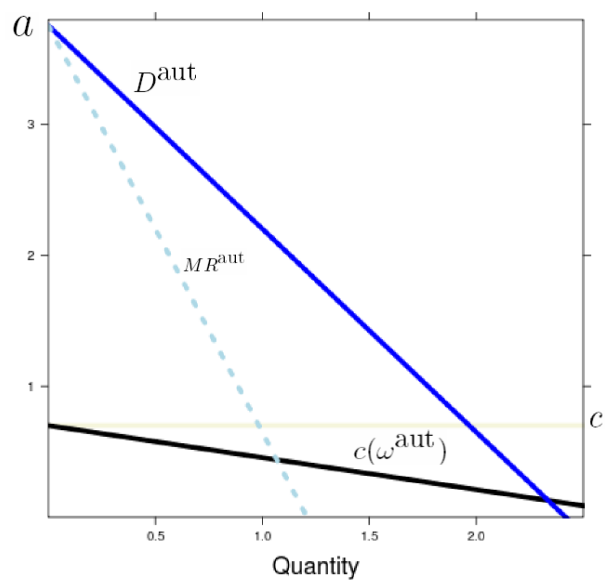
The marginal revenue includes $\gamma hq/L$ and shows branded multiproduct firms reduce their quantities in anticipation of cannibalization of old products. Figure 2.1 illustrates optimal quantity choice.

[11] The view of process innovation as vertical differentiation (more quantity per unit cost) and product innovation as horizontal differentiation is similar to Eswaran and Gallini (1996). Firms may increase or decrease investments in product and process innovation. Product innovation refers to a rise in product variety and not to improvements in product "quality" (which yields more utility-effective quantity per unit cost). For a related literature on quality, the reader may refer to Kugler and Verhoogen (2007), Hallak and Sivadasan (2006) and Eckel et al. (2009).

[12] I allow firms to choose a production process for each product. Results are similar for intermediate levels of product-specificity of process R&D costs. In the extreme case of costless application of the production process to all products of the firm, my model collapses to the standard case where product and process innovation only vary on the cost side and not the demand side.

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 and slope $-(\delta+\gamma h)/L$. As usual, optimal quantity per product is determined by the intersection of the marginal revenue MR and marginal cost $c(\omega)$ curves. The difference is that the slope of the marginal revenue curve reflects both the own price effects and the brand-wide price effect. The marginal cost curve includes the cost saving from process innovation. The optimized $c(\omega)$ is downward-sloping as higher quantities make it more profitable to undertake process innovation.

FIGURE 2.1. Optimal Quantity Choice



Equation (2.3) and the inverse demand determine the optimal markup charged by the firm. Substituting for optimal quantity optimal quantity $q=L(a-c(\omega))/2(\delta+\gamma h)$ and optimal process $\omega=(cq/2r_\omega)^2$, 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, optimal 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, branded 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 so multiproduct firms charge lower markups. 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. I will revisit this point when studying the impact of trade.

2.2.3. *Product Range.* At the optimal product range, profit from a new product π is equal to the fall in profit from cannibalization of old products. Adding a new product reduces the price of each old product by $dp/dh = \gamma q/L$, resulting in total cannibalization of $h(\gamma q/L)q$. The FOC for product range h is

$$\frac{\partial \Pi}{\partial h} = \pi - \underbrace{h(\gamma q/L)q}_{\text{Cannib. Effect}} = 0 \tag{2.4}$$

Equation (2.4) shows that the net marginal benefit from the new product falls with intra-brand cannibalization γ, given other firm decisions (q and ω). Unlike process innovation, product innovation directly cannibalizes. Formally, $\partial h(q,\omega,\gamma)/\partial\gamma < 0$ while $\partial\omega(q,\gamma)/\partial\gamma = 0$.

Product innovation can be interpreted as an instrument for firms to adjust demand elasticities. Equation (2.4) reflects a tradeoff between profits from a new product and higher elasticities of all old products, $\pi - h\pi'(\varepsilon)\partial\varepsilon/\partial h = 0$. So product innovation enables firms to choose its optimal demand elasticity. A similar interpretation is given to "perceived quality" and horizontal differentiation in advertising and industrial organization (e.g. Dixit 1979, Rosenkranz 2003).

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 industry equilibrium.

A firm introduces new products till the profit from a new product net of its cannibalizing effect is driven to zero. Consequently, Equation (2.4) is a zero-profit condition (ZPC). Profit per product is $\pi = [p - c(\omega)]q - r_\omega\omega - r_h$. Substituting for optimal markups and process, $\pi = (\delta + \gamma h)q^2/L - (c^2/4r_\omega)q^2 - r_h$ and the ZPC is:

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

The ZPC determines equilibrium quantity per product $q^{\text{aut}} = r_h^{1/2}/(\delta/L - c^2/4r_\omega)^{1/2}$. 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.

Substituting for optimal quantity, process innovation is $\omega^{\text{aut}} = [cq^{\text{aut}}/2r_\omega]^2 = (c/2r_\omega)^2 r_h/(\delta/L - c^2/4r_\omega)$. Optimal process 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).

Unlike process innovation, product innovation cannibalizes directly and indirectly (i.e. $dh^{\text{aut}}/d\gamma < 0$). In equilibrium, free entry ensures each firm earns zero profit implying $\Pi = h\pi - f = 0$. From

Equation (2.4), firms ensure that profit per product π equals the cannibalization effect $\gamma hq^2/L$. Consequently, the free entry condition (FE) is:

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

Substituting for q^{aut} 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-brand cannibalization γ. I summarize these 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* $\partial\omega(q,\gamma)/\partial\gamma = d\omega/d\gamma = 0$.

Proposition 1 shows that an exogenous rise in the degree of intra-brand cannibalization (γ) does not alter process decisions of firms but lowers their product range. To understand this, it is useful to re-interpret firm decisions as choosing the optimal process ω, quantity q and cannibalization $b \equiv \gamma hq$. If γ rises, b rises and the firm must re-optimize. Cannibalization does not directly affect ω so a rise in γ leaves the optimal process choice unaffected; the process FOC is unchanged. The original quantity will also be optimal if the firm can lower h by an equivalent amount to keep b unchanged. With b unchanged, prices and profit lost from cannibalization are unaffected so the product range FOC holds with the new lower product range. Firms adjust to a rise in the degree of cannibalization γ through the extensive margin of products rather than the intensive margin of quantities and processes. Intuitively, this occurs because prices are more sensitive to cannibalization than marginal revenue. Product range is determined by price (through profit of the marginal product) while quantity is determined by marginal revenue of each product. Consequently, a rise in γ lowers returns to product innovation more than returns to quantities and process innovation. As a result, firms adjust to increases in γ through products and cannibalization does not play a role in process innovation.

Equating the inverse demand function to the optimal price chosen by the firm, the mass of firms can be solved 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 equilibrium product range h declines with L, total product variety increases due to more firms operating in bigger markets.

2.4. **Open Economy.** I examine how trade affects 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, there are no fixed costs of exporting and the firm problem is

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

FOCs for the firm problem are similar to those in autarky. From the firm's FOC for process choice, optimal production process is determined by $-c'(\omega)(q+q^x) = r_\omega$. 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. By symmetry of costs, firms choose to supply the same product range to both home and foreign markets. 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. After opening to trade, the ZPC is $\pi - \gamma h q^2/L - \gamma h (q^x)^2/L = (\delta/L)(q^2 + (q^x)^2) - (c^2/4r_\omega)(q+q^x)^2 - r_h = 0$. 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 condition under free trade is:

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

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 $h\pi = \gamma h^2 q^2/L + \gamma h (q^x)^2/L = f$. Substituting for $q^x = q$, the FE condition under free trade is:

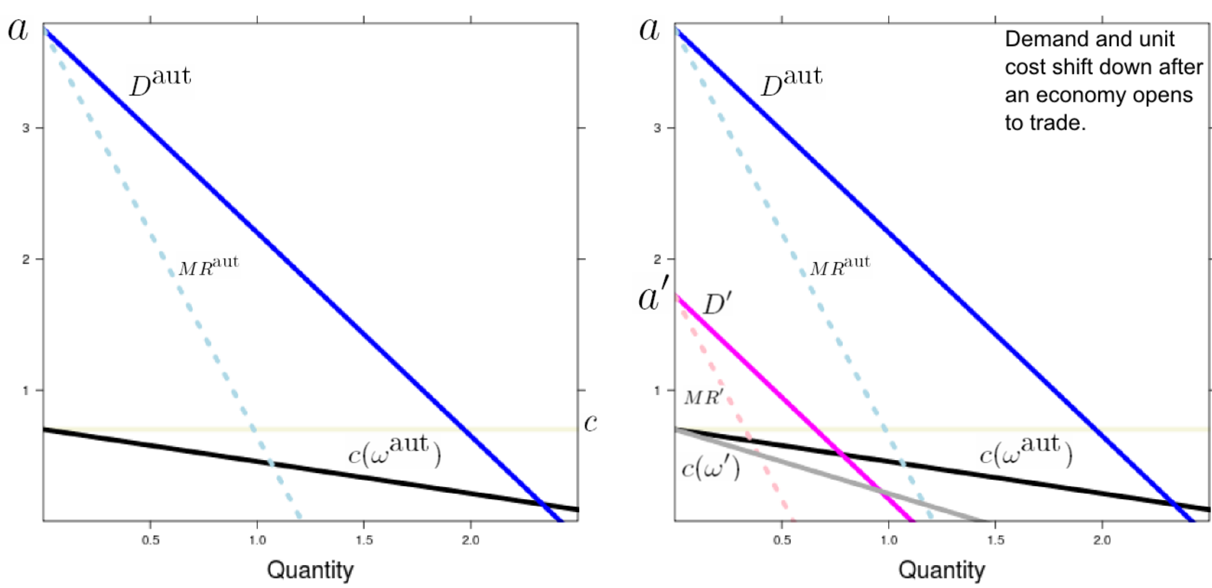
(FE') $$h\pi = \gamma h^2 (2q)^2/2L = f$$

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. From the ZPC' condition, total quantity per product ($2q$) rises after trade ($q + q^x = 2q > q^{\text{aut}}$) providing economies of scale. Consequently, firms increase their process innovation to $\omega^{\text{open}} = [c(2q)/2r_\omega]^2 = (c/2r_\omega)^2 r_h/(\delta/2L - c^2/4r_\omega) > \omega^{\text{aut}}$. Substituting for optimal quantity, FE' shows that product innovation drops to $h^{\text{open}} = [2Lf/\gamma(2q)^2]^{1/2} = [2Lf(\delta/2L - c^2/4r_\omega)/\gamma r_h]^{1/2} < h^{\text{aut}}$. Firms engage in more process innovation at the expense of product innovation. I discuss the underlying economic reason and then proceed to welfare gains from trade.

2.4.2. *Impact of Trade on Innovation.* Trade increases the size of the home market which produces two effects: a market expansion effect and a product market competition effect. These two effects have opposing implications for firm innovation. I discuss each in turn.

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 the total quantity of each product as well as the marginal product. Consequently, access to foreign market provides firms with an incentive to increase both product and process innovation. As shown in Figure 2.2 B, the marginal cost curve shifts down from $c(\omega^{\text{aut}}) = c(\omega(q))$ to $c(\omega') = c(\omega(q + q^x))$ after free trade. For ease of reference, the autarky figure is reproduced in Panel A and changes after trade are shown in Panel B.

FIGURE 2.2. Direct Impact of Trade on Residual Home Demand



(A) Autarky (B) Free Trade

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. This lowers the demand intercept $a \equiv \alpha - \eta Q/L$ as shown in Figure 2.2 B. Home demand for firm j's product i shifts down from D^{aut} to D'. The downward shift increases demand elasticities and lowers profitability. Firms counteract this rise in external competition by lowering internal competition through lower product innovation. Cutting product lines lowers the level of cannibalization. At the same time, it has a positive effect on prices implying profit per product increases. This fall in product innovation can also be interpreted in terms of demand elasticities. Unlike the CES case, trade increases demand elasticities (through a) and firms counteract the rise in elasticities by cutting product lines.[13]

[13]The reason for lowering product innovation can be understood from the response of the ZPC condition to a rise in market size L. ZPC is $\pi - \gamma h q^2/L = 0$ implying product innovation is determined by change in profit from the marginal product relative to cannibalization, i.e. $d\pi/dL - d(\gamma h q^2/L)/dL = 0$. Profit per product is $\pi = [a - c(\omega) - \delta q/L -$

2.4.3. *Impact of Trade on Welfare.* Innovation affects welfare through variety and prices. The indirect utility function is $V \equiv 1 + Mh(\alpha - p)/2(\delta + \gamma h + \eta Mh)$. Lower product innovation reduces product variety and has a negative effect on welfare. However, consumers do not experience a reduction in total available variety Mh. They gain access to foreign brands and enjoy welfare gains from increase in variety. Welfare from variety rises for another reason. After trade, consumers enjoy access to more brands rather than many varieties from a few brands. Therefore, the product space features more differentiated varieties and V rises due to a fall in γh. The fall in γh and rise in Mh yield Gains from Variety.

Rise in product variety lowers residual demand for each product and induces firms to lower their prices. Competitive pressure drives down markups. Markup is $\mu = (\delta + \gamma h)q/L$ which declines as both h and q/L fall. Reduction in markups is accompanied by greater process innovation ω. Firms attain cost savings ($c(\omega)$ falls) and pass them to consumers, resulting in Gains from Lower Prices. I summarize the impact of trade on innovation and welfare in Proposition 2.

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

2.4.4. *Bilateral and Unilateral Tariff Changes.* Moving beyond free trade, 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 $t = t^* > 0$.

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 $s \equiv (1+\theta)^2/(1+\theta^2)$. As earlier, the FOCs for supply to the home and foreign markets 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 so the export to home production ratio is $\theta \equiv q^x/q = (a^* - t^* - c)/(a-c)$ which need not equal one. This export to home production ratio θ is a useful statistic that captures the firm-specific increase in market size from trade. As θ rises, size factor s rises implying firms experience an increase in the market size available to them.

A bilateral tariff liberalization reduces tariffs in both countries and increases the export to domestic production ratios of home and foreign firms. This rise in θ and θ^* increases the market size

$\gamma hq/L]q - r_\omega \omega - r_h$ implying $d\pi/dL = qda/dL - (\gamma q^2/L)(dh/dL)$ from the envelope theorem. Rise in market size increases competition so $da/dL = -(\delta + \gamma h)q/L^2 < 0$ from the FE condition. Substituting for da/dL and $\gamma(hq)^2/L = f$ from FE, the ZPC gives $(\gamma q^2/L)(dh/dL) = qda/dL$. Thus $dh/dL < 0$ and cutting product lines enables firms to face tougher competition by lowering cannibalization. In models with CES demand, the negative impact of trade on product innovation arises due to increasing costs of product innovation or rising marginal cost of additional products. I have closed these channels so product adjustments work only through the interaction between competition and cannibalization (and not through cost linkages).

available to home and foreign firms, resulting in innovation responses similar to free trade. Firms increase their process innovation but reduce their product innovation. A unilateral foreign tariff liberalization reduces the tariff faced by home exporters in the foreign country and also induces similar innovation responses among home firms. 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 liberalizing foreign economy. Competition falls due to this de-location, resulting in an improvement in industry-wide demand conditions abroad a^*. The indirect impact of a fall in a and a rise in a^* reinforces the rise in market size for home firms 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 cut induces exactly the opposite innovation responses among home firms. While it does not directly affect θ, a unilateral home tariff cut directly increases foreign firm's export share θ^*. With a rise in θ^*, foreign firms expect a rise in market size available to them. This implies more entry and tougher competition in the foreign market, leading to a deterioration in industry-wide demand conditions a^*. In the home market, firms expect a fall in market size available to them due to higher imports at home. 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 exporters experience a rise in market size at the expense of home exporters. 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 lowers market size for home firms and induces the opposite innovation responses; home firms increase product innovation and lower process innovation. 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 on home firms.*

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 complementary explanation for the fall in product innovation of US firms due to CUSFTA (Bernard et al. 2006). Though not unique to this paper, the contrasting effects of foreign and home tariff cuts are noteworthy. Head and Ries (1999) find the size of Canadian establishments declined due to Canadian tariff cuts but increased due to US tariff cuts, a finding which is consistent with my model. Goldberg et al. (2009) and Kochhar et al. (2006) show product innovation rose while production scale fell among Indian firms after 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. For example, small Canadian firms lowered product innovation while large Canadian exporters increased product innovation during CUSFTA (Baldwin and Gu 2005). 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 produce a brand of products with cost draw c. The cost draw is no longer deterministic. 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 entry costs. Having paid the entry cost, each firm observes its cost draw c.[14] It decides 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 tractability and empirical conformity. The only difference from the homogeneous firm case is that the process decision does not involve choosing the level of upgrading. This simplifies the analysis without sacrificing richness in model predictions. By paying r_ω, a firm with initial cost draw c can upgrade its process to $c - \omega(c)$ with $\omega'(c) \leq 0$.[15] Consequently, the firm problem is:

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

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

Optimal choices of process, quantities and products are determined in a manner similar to Section 2. Consequently, I relegate details to the Appendix and summarize useful notation here. Let (x,ω) denote the exporting and process innovation decisions where $(x,\omega) = (0,1)$ refers to a non-exporter that undertakes process innovation. Then $\Pi_{x\omega}(c)$ denotes the profit of a firm with initial cost draw c that adopts strategy (x,ω). A non-exporting firm that is indifferent between not upgrading and upgrading its process is denoted by $c_{00,01}$ where $\Pi_{01}(c_{00,01}) = \Pi_{00}(c_{00,01})$. Similarly, let $c_{10,11}$ refer to an exporter that is indifferent between not upgrading and upgrading its process so that $\Pi_{11}(c_{10,11}) = \Pi_{10}(c_{10,11})$. With this notation in hand, I proceed to a discussion of the impact of trade liberalization on innovation.

[14] I abstract from within-firm heterogeneity and rising costs of product innovation to simplify the analysis and show that changes in product range are not driven by cost linkages.

[15] I assume returns to process innovation are increasing in initial productivity as in the empirical findings of Bustos (2009)and Bas (2008). The results presented in this Section are also valid with decreasing returns as implied by Nocke and Yeaple (2005). In an online Appendix, I show different assumptions on returns to process innovation yield different predictions regarding which firms innovate based on initial productivity (as opposed to initial export status which is the focus of this Section). I also discuss the relation with the literature on distance to the productivity frontier.

3.1. **The Impact of Trade Liberalization on Innovation.** 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 ($s(c) = (1+\theta(c))^2/(1+\theta(c)^2)$) differs across firms. Continuing non-exporters do not experience any change in scale economies. Their market size is unchanged as their exports q^x continue to be zero. This implies their export to domestic production ratio $\theta = q^x/q$ continues to be zero so their scale factor s is unaffected after trade. Consequently, non-exporters do not change their process decisions. However, they are adversely affected by tougher competition in the home market. Fall in aggregate home market conditions a shifts the residual demand downwards so non-exporters respond by cutting back on product lines. Formally, the indifference costs for process innovation do not change after trade ($c^{\text{aut}}_{00,01} = c^{\text{open}}_{00,01}$ and $c^{\text{aut}}_{00,11} = c^{\text{open}}_{00,11}$) while the product variety offered by non-exporters falls after trade ($h^{\text{aut}}_{0\omega}(c) > h^{\text{open}}_{0\omega}(c)$). The full force of tougher competition is realized in the form of lower product range rather than lower quantity per product. This is not due to discrete process choice, rather due to the differential effects of trade on the returns to innovation. The reasoning is similar to that for exogenous changes in cannibalization. Price is more sensitive to industry demand conditions implying that returns to product innovation decline more than returns to quantity expansion. As a result, non-exporters adjust to tougher competition by narrowing their product range.

Exporters experience an expansion in market size and find it easier to engage in process innovation ($c^{\text{aut}}_{10,11} < c^{\text{open}}_{10,11}$). At the same time, they face tougher competition due to more entry in a bigger market. The relative strength of the market expansion and competition effects in determining product innovation depends on the extent of export orientation of each firm. Average export orientation of the home economy ($\tilde{\theta}$) is the ratio of total exports to domestic supply of home firms (Q^x/Q). 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 ($\theta > \tilde{\theta}$). 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. Consequently, small exporters cut back on product lines to counteract the rise in demand elasticities. Large exporters are the big gainers from market expansion. They corner a large fraction of the export market and are able to absorb higher intra-brand cannibalization from more product lines. Large exporters increase product innovation. Formally, $h^{\text{aut}} < h^{\text{open}}$ if $\theta < \tilde{\theta}$ and $h^{\text{aut}} > h^{\text{open}}$ if $\theta > \tilde{\theta}$.

Having determined innovation responses to free trade, I consider the empirically relevant cases of bilateral and unilateral tariff liberalization. As earlier, a bilateral tariff liberalization, a fall in foreign tariff or a rise in home tariff expands the market size available to home exporters and produces effects similar to free trade. With a unilateral foreign tariff cut or a home tariff rise, home market conditions deteriorate (a falls) while foreign market conditions improve ($a^* - t^*$ rises). I study the impact of these changes on home firms. Non-exporters face tougher competition at home but experience no market expansion (as θ and hence s continue to be zero). They reduce their product lines and do not change their process choice, i.e. $dh_{0\omega}/dt^* > 0, dh_{0\omega}/dt < 0$ and $dc_{00,x1}/dt^*, dc_{00,x1}/dt = 0$. Exporters experience a market expansion as $dq^x/dt^* < 0$ and $dq^x/dt > 0$. This implies an increase in their export to domestic production ratio θ and hence a rise in their scale factor s. Expansion in available market size induces exporters to engage in more process innovation. Small exporters supply mostly to the domestic market implying they benefit little from better market conditions abroad (as θ is low for small exporters). 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. Specifically, $\text{sign} dh_{1\omega}/dt^* = \text{sign}(\tilde{\theta} - \theta)$ and $\text{sign} dh_{1\omega}/dt = \text{sign}(\theta - \tilde{\theta})$.

These results differ from recent work on multiproduct firms. The literature on multiproduct firms explains differences in products sold to different markets so the focus is on within-firm heterogeneity and selection of better products as the driving force for observed increases in productivity. Though my question is different, the model has implications for productivity and products. As in Bernard et al. (2006) and Mayer et al. (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). Therefore, productivity of non-exporters is not affected. Bernard et al. and Mayer et al. find instead that all firms show higher revenue-based productivity as they drop their marginal products. I find that decisions to drop products vary by export orientation of firms. For ease of reference, my results are summarized in Proposition 4.

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

Proposition 4 shows that product and process innovation move in the same direction for large exporters but in opposite directions for small exporters. Thus product and process innovation reflect complementarities for large exporters (as in Athey and Schmutzler 1995) but substitutability for small exporters (as in Eswaran and Gallini 1996). As mentioned earlier, this heterogeneity in firm responses is consistent with differences in product innovation among Canadian firms during CUSFTA (Baldwin and Gu 2005). Notably, Lileeva and Trefler (2010) find productivity gains of Canadian plants are positively related to output *per product*, suggesting a role for scale economies at the product level. Within Argentinean manufacturing, Bustos (2009) finds the expected result that foreign tariff cuts induce exporters to engage in greater product and process innovation, relative to non-exporters.[16] Similarly, Iacovone and Javorcik (2010) show that existing Mexican exporters increased product variety by more than new exporters after the US tariff cuts of NAFTA. They also find higher investments in physical capital among exporters, relative to non-exporters. These studies consider bilateral trade liberalization but a related literature on plant size provides supporting evidence for unilateral trade liberalization. In my model, a home tariff cut induces small exporters and non-exporters to engage in product innovation and expand plant size ($h(q+q^x)$). Indeed, Tybout et al. (1991) find that lower protection enabled small Chilean plants to expand output and the plant size distribution became more uniform in industries experiencing large home tariff cuts.

3.2. **Testable Results for Trade Liberalization, Innovation and Exporting.** In this sub-section, I systematically outline the testable results arising from Proposition 4. I consider two types of predictions: the relationship between trade liberalization and innovation and the theoretical channel of exporting through which trade liberalization affects innovation.

Trade Liberalization and Innovation

1. *Initial Export Status and Process Innovation.* With a foreign tariff cut, firms that initially exported are more likely to undertake process innovation, relative to non-exporters. This follows from $dc_{10,11}/dt^* < 0$ while $dc_{00,x1}/dt^* = 0$. With a home tariff cut, firms that initially exported are less likely to undertake process innovation as $dc_{10,11}/dt > 0$ and $dc_{00,x1}/dt = 0$.

2. *Initial Export Orientation, Cannibalization and Product Innovation.* For firms facing intra-brand cannibalization, a fall in foreign tariffs lowers product innovation for non-exporters and small exporters ($\theta < \tilde{\theta}$) and increases product innovation for large exporters ($\theta > \tilde{\theta}$). With a fall in home tariffs, product innovation rises for non-exporters and small exporters and falls for large exporters. This follows from $dh_{0\omega}/dt^* > 0$ and $\text{sign} dh_{1\omega}/dt^* = \text{sign}(\tilde{\theta} - \theta)$ while $dh_{0\omega}/dt < 0$ and $\text{sign} dh_{1\omega}/dt = \text{sign}(\theta - \tilde{\theta})$.

Trade Liberalization, Exporting and Innovation

1. *Change in Exports Per Product and Process Innovation.* With a foreign tariff cut, firms that experience a rise in export scale (q^x) are more likely to undertake process innovation. With a home tariff cut, firms that experience a fall in export scale are less likely to undertake process innovation. Specifically, $c_{10,11}$ and q^x rise with a fall in t^* while $c_{10,11}$ and q^x fall with a fall in t.[17]

[16] The product innovation measure of Bustos includes both new products and "technological improvement of existing products." Similarly, Teshima (2008) includes product quality upgrades in his product R&D measure of Mexican firms. He shows Mexican tariffs are positively correlated with process R&D but statistically uncorrelated with product R&D in 2000-2003. Unfortunately, it is difficult to interpret his findings in the context of my model for two reasons. First, quality upgrades are not isomorphic to introduction of new products in my model. Second, Mexican tariff changes may be correlated with US tariff changes during the period.

[17] With a continuous process choice, this result can be summarized as $\text{sign} d\omega/dt^* = \text{sign} d\theta/dt^*$ which is zero for non-exporters and negative for exporters. Similarly, $\text{sign} d\omega/dt = \text{sign} d\theta/dt$ which is zero for non-exporters and positive for exporters.

2. *Change in Export Orientation and Product Innovation.* With a fall in foreign tariffs, firms that increase their export orientation are able to increase product innovation. A fall in home tariff lowers export orientation and raises product innovation. This follows from $dh_{x\omega}/d\theta_{x\omega} < 0$, $d\theta_{x\omega}/dt^* < 0$ and $d\theta_{x\omega}/dt > 0$.

4. Application of Testable Results to Innovation in Thailand

In this Section, I examine whether the theory provides an empirically relevant framework to study the impact of trade policy on firm innovation. I examine innovation among Thai manufacturing firms in response to unilateral home tariff changes during 2003-2006. The focus on Thai manufacturing is motivated by availability of direct innovation data and substantial tariff variation. I start with an explanation of data sources, innovation variables and tariff changes in the Thai context. Then I test the predictions of Section 3 and discuss the main results.

4.1. **Data.** Thai manufacturing data are from the 2004 and 2007 rounds of the Thailand Productivity and Investment Climate Surveys (PICS). These establishment 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 2004 and 2007 rounds of the PICS randomly sampled Thai manufacturing establishments spanning 34 ISIC 4-digit industries. Among these establishments, 426 incumbents that started operations before 2003 were interviewed in both the 2004 and 2007 rounds. To examine within-firm product and process responses, I focus on these incumbents. The majority of incumbents belong to Textiles and Garments and Rubber and Plastics. About 60 per cent of these incumbents exported in 2006 and 88 per cent reported making more than one type of product.

While the survey contains rich information on innovation and production characteristics, it has its limitations. As is standard, most information is available at the establishment level and not at the firm level. To address this issue, I use both establishment and firm-level variables to ensure robustness of key 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 a single plant in a given industry. About 87 per cent of the establishments are not divisions of larger firms. All results presented in the next Section are robust to controls for multiplant firms.

4.2. **Innovation Variables.** I first explain the innovation measures and then discuss their relevance for the current analysis. Innovation measures are constructed as follows. I use three measures of process innovation after the Thai tariff changes. For the baseline results, an incumbent is a process innovator (coded as 1) if it "introduced new technology that has substantially changed the way the main product is produced" in 2005-2006. This indicator is a direct measure of process innovation and has the advantage of a straightforward mapping to the theoretical concept of process innovation ω. However, it has the disadvantage of not capturing differences in intensity of innovation across firms. Consequently, I also consider firm expenditure on new machinery and equipment (M&E). Note that "new" does not refer to M&E that is second-hand, implying this measure embodies new technologies. In fact, two-thirds of the incumbents reported that investing in new M&E is a leading way of acquiring technological innovations. I use change in firm expenditure on New M&E between 2002 and 2006 (ME_6/ME_2) to capture the change in intensity of technological investments before and after the tariff changes. A key issue is that many firms do not invest in New M&E in either year, implying that the level of technological investments may be more important than the change. Consequently, I also examine the level of firm investments in New M&E during 2005-2006 (ME_{56}). Among incumbents, 29 per cent do not add any New M&E in 2005-6 while the remaining are process innovators with a positive percentage of New M&E. As results are similar, I only report the baseline specification for these second and third measures of process innovation.

I use three measures of product innovation after the Thai tariff changes. For the baseline estimation, a firm is a product innovator (coded as 1) if it increased its product range either by adding new products or new plants in 2005-2006. I explain each part in turn. First, product innovation is based on self-reported product changes of firms (and not on counts of product codes). This has the advantage of capturing finer product categorizations which are of interest in studying cannibalization. However, this raises concerns regarding reporting bias based on size of firms. To minimize this problem, the product innovation variable draws on direct "Yes/No" questions indicating whether the establishment "Developed a major new product line" or "Discontinued at least one product (not production) line" and balance sheet data (containing sales of main products).[18] Second, plant openings and closings are included to 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 a continuing product. To account for this, I exclude opening and closing of plants and find that the product innovation measure changes for only thirteen firms. Key results are similar when plant openings and closings are considered to be distinct from changes in product range.

As a robustness check, I consider two investment based measures of product innovation. First, I proxy for product innovation by the rise in number of workers used exclusively for design innovation/R&D from 2002/3 to 2006 (D_6/D_2). This captures the change in intensity of product investments before and after the tariff changes. Only a quarter of the incumbents employ any design workers so I also consider the level of design workers at the establishment in 2006 (D_6).

Focusing on incumbent firms between 2002 to 2006, Table 1 provides a summary of process innovators and product innovators for the baseline indicators. About a quarter of the incumbents

[18] I am grateful to Andy Bernard for pointing this out. I do not observe product codes for more than one product but the survey asks for a list of sales of the top products sold.

engage in both product and process innovation. A concern with looking at different dimensions of innovation is that one type of innovation may be necessary for another type of innovation. However, 37 per cent of the incumbents undertake only one type of innovation which shows that product and process innovation are not necessarily coupled.[19]

TABLE 1. Prevalence Rates for Product and Process Innovation

Percentage of Incumbents by Innovation Status			
Product & Process	Only Product	Only Process	None
24	11.5	25.5	39

4.3. **Thai Trade, Manufacturing and Trade Policy.** In this sub-section, I provide a brief overview of Thai trade, manufacturing and trade policy between 2003-2006. Manufacturing accounts for over two-thirds of Thai trade. Within manufacturing, Thailand's major trade partners are the group of East Asian countries (about 30%) comprising of the ASEAN nations, Hong Kong, Korea and Taiwan (Source: UNCTAD TRAINS). During the period under consideration, Thai exports grew more slowly than imports and East Asian countries continued to dominate Thai trade.

Tariffs are the main source of trade protection in Thailand. Between 2003-2006, the Thai government restructured its tariff regime, leading to tariff cuts in over a third of the tariff lines (The WTO 2007). For the manufacturing sector under consideration, the average applied tariff declined from 60 per cent in 2003 to 48 per cent in 2005-6 (weighted by firm revenue). I focus on applied rates as they capture the extent to which tariffs change exporting costs in practice. This is particularly important for Thailand because a quarter of all Thai tariff lines are not bound. Bound rates are considerably higher than applied tariff rates which can be changed at any time (up to the bound rates) through executive notifications.

Summary statistics for the percentage fall in effectively applied tariff rates of Thailand and its trading partners are given in Table 2 (definitions are in the Appendix). 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

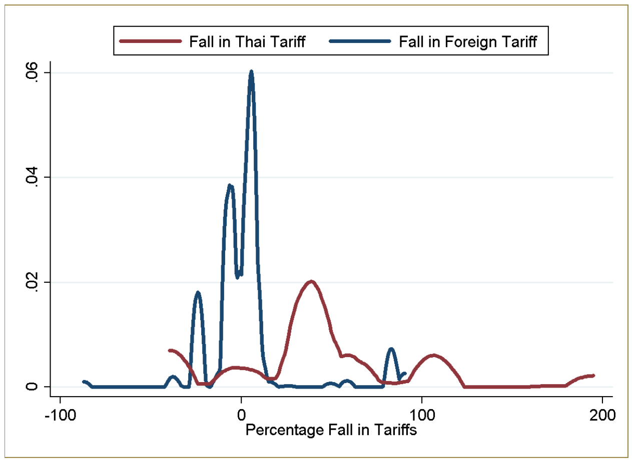
Fall in Tariffs	Mean	S.D.	Min	Max	ΔTariff $< 10\%$
Home tariffs Δt	43.9	56	-40	195	6% of sample
Foreign tariffs Δt^*	3.9	32	-108	103	60% of sample

As shown in Table 2, Thai tariffs vary much more than foreign tariffs. The standard deviation of home tariffs is twice that of foreign tariffs. Sixty per cent of the sampled firms experience a

[19]The process innovation question is product-specific so it is unlikely that process innovation was necessary for expansion of the product range. It is hoped that future innovation surveys will address the reasons more explicitly.

change in foreign tariffs of less than 10 per cent as opposed to just six per cent for home tariffs. A visual summary of tariff changes is provided in Figure 4.1 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 195 per cent. Foreign tariff changes show a peak near zero while Thai tariff changes reflect substantial cross-industry variation. Consequently, I focus on Thai tariff changes and exploit the cross-industry variation to examine the theoretical predictions for innovation.

FIGURE 4.1. Distributions of Fall in Thai and Foreign Tariffs from 2003 to 2005-2006



4.4. **Impact of Thai Tariff Cuts on Innovation.** This sub-section empirically examines the testable predictions of Section 3. I start with the impact of trade liberalization on innovation and proceed to the channel of exporting through which trade affects innovation.

4.4.1. *Initial Export Status and Process Innovation.* Let $\Delta\omega_{jn}$ denote process innovation of firm j in sector n and Δt_n denote the fall in Thai tariffs of industry n. Positive values refer to tariff cuts while negative values refer to increases. Let $E_j = 1$ if firm j exports in the initial period of 2002. With a fall in Thai tariff, firms that initially exported are less likely to undertake process innovation. To test this hypothesis, process innovation of firm j in industry n is

$$\Delta\omega_{jn} = \beta_1 \Delta t_n + \beta_2 E_j \cdot \Delta t_n + \zeta Z_j + \varepsilon_{jn} \tag{4.1}$$

where Z_j is a vector of controls including exporter-sector dummies and other firm and industry characteristics. Note that a sector refers to a broader product code than an industry so there is no identification problem in this regard.

A home tariff cut benefits foreign exporters at the expense of home exporters. Exports per product of home firms drop and they experience lower economies of scale. This implies exporters reduce process innovation in response to home tariff cuts. As process innovation may be related to tariff cuts for other reasons, I do not emphasize the level relationship between tariff cuts and process innovation. Instead, I focus on the difference in the relationship for exporters and non-exporters. The parameter of interest is β_2 which is expected to be negative, implying that exporters undertake lower process innovation than non-exporters after a Thai tariff cut.

TABLE 3. Process Innovation and Tariffs

Process innovation		(a) Coef. (Std. Err.)	(b) Coef. (Std. Err.)	(c) Coef. (Std. Err.)	(d) Coef. (Std. Err.)	(e) Coef. (Std. Err.)	(f) Coef. (Std. Err.)
Fall in Thai Tariff Δt		0.412^{*}	$0.343^{\dagger}$	$0.322^{\dagger}$	0.040	6.252^{**}	3.633^{**}
		(0.194)	(0.183)	(0.187)	(0.158)	(0.829)	(1.324)
Exporter$\cdot\Delta t$	**($\beta_2 < 0$)**	-0.551^{*}	$-0.512^{\dagger}$	$-0.475^{\dagger}$	-0.604^{*}	-6.340^{*}	-5.012^{**}
		(0.257)	(0.263)	(0.262)	(0.294)	(2.476)	(1.474)
Sales			0.075	0.053	0.120		
			(0.080)	(0.078)	(0.085)		
Permanent workers			$0.289^{\dagger}$	$0.291^{\dagger}$	0.266		
			(0.161)	(0.164)	(0.172)		
Unskilled production workers			-0.052	-0.051	-0.070		
			(0.080)	(0.083)	(0.083)		
Multiple plants in industry			0.150^{*}	0.146^{*}	$0.126^{\dagger}$		
			(0.073)	(0.073)	(0.076)		
Learn new tech from MNC				0.514^{*}			
				(0.224)			
Tech program of MNC				0.065			
				(0.180)			
Fall in import duty on M&E					0.168^{**}		
					(0.045)		
Exporter-Sector dummies		yes	yes	yes	yes	yes	yes
N		423	421	421	405	426	426
Log-likelihood		-277.653	-259.444	-259.900	-248.123	0.048	0.104

Notes: **, *and †denote 1, 5 and 10 per cent significance levels. In Columns a to d, the LHS variable is 1 if an establishment "Introduced new technology that has substantially changed the way the main product is produced" in 2005-2006 and 0 otherwise. The LHS variable in Column e is Rise in New Machinery and Equipment Investment (ME_6/ME_2) and New Machinery and Equipment Investments during 2005-2006 (ME_{56}) in Column f.

I estimate Equation (4.1) using the process innovation indicator. As the indicator is a binary dependent variable, Equation (4.1) is estimated as a probit regression in Column (a) of Table 3. The quantitative measures based on new M&E have a continuous range so I use OLS with exporter-sector dummies in Columns (e) and (f) of Table 3. Standard errors are robust to heteroskedasticity and clustered by exporter-industry status. As expected, Table 3 shows exporters in industries with larger tariff cuts are less likely to undertake process innovation $\beta_2 < 0$. Importantly, these exporters are less innovative after the tariff cut both in absolute terms as $\beta_1 + \beta_2 < 0$ and relative to non-exporters as $\beta_2 < 0$. Non-exporters respond positively $\beta_1 > 0$ but the magnitude and statistical significance of this estimate declines after adding more controls.

4.4.2. *Initial Export Orientation, Cannibalization and Product Innovation.* Let Δh_{jn} denote product innovation of firm j in sector n and ES_j denote its initial export share ($\theta/(1+\theta)$ in 2002). To test the product innovation predictions, I consider branding status and adapt the reduced form estimation of Baldwin and Gu (2004) and Bernard et al. (2006) to account for the disparate impact arising from brand effects. Intra-brand cannibalization is expected to play a role for firms that differentiate their products through branding. In fact, Hui (2004) estimates demand for personal computers and finds that "the threat of cannibalization is indeed imminent for branded multiproduct firms" but firms whose brand value is yet to be established do not face this threat. Consequently, I focus on product innovation of firms with branded products relative to firms without branded products. I observe whether firms brand their products and define $B_j = 1$ if a firm answered that it had its own brand and 0 if it did not have a brand. About 59 per cent of incumbents brand their products in 2002 and 2006. I expect the predictions of the model to apply to firms making branded products and estimate product innovation of firm j in industry n as

$$\Delta h_{jn} = \beta_1 \Delta t_n + \beta_2 ES_j \cdot \Delta t_n + \beta_3 B_j \cdot \Delta t_n + \beta_4 B_j \cdot ES_j \cdot \Delta t_n + \zeta Z_j + \varepsilon_{jn} \tag{4.2}$$

where Z_j is a vector of controls including brand-sector dummies, export shares ES_j, interaction of brand and export shares $B_j \cdot ES_j$ and other firm and industry characteristics. I interact tariff changes with export shares to allow the slopes to vary by export orientation. Interacting tariff reductions with export shares avoids sensitivity problems associated with cutoffs for large exporters. Among firms making branded products, small exporters and non-exporters are expected to increase product innovation ($\beta_3 > 0$) while large exporters are expected to cut back on product innovation ($\beta_4 < 0$). Consequently, I test whether $\beta_3 > 0$ and $\beta_4 < 0$. A more stringent prediction is $\beta_1 + \beta_3 > 0$ and $\beta_2 + \beta_4 < 0$.

For the baseline results, Equation 4.2 is estimated as a probit regression using the binary product indicator in Column (a) of Table 4. For the quantitative measures based on design workers, I use OLS with brand-sector dummies in Columns (e) and (f) of Table 4. Standard errors are robust to heteroskedasticity and clustered by brand-industry status. Table 4 shows firms selling branded products have a positive relationship between investment in product innovation and Thai tariff cuts at low levels of export shares $\beta_3 > 0$ and a negative relationship at high levels of export shares $\beta_4 < 0$. In industries with larger tariff cuts, branded firms are more innovative at low export shares both in absolute terms $\beta_1 + \beta_3 > 0$ and relative to their unbranded counterparts $\beta_3 > 0$. Similarly, branded firms are less innovative at high export shares both in absolute terms $\beta_2 + \beta_4 < 0$ and relative to unbranded firms with high export shares $\beta_4 < 0$.

4.4.3. *Change in Exports Per Product and Process Innovation.* I examine whether the underlying mechanism of change in exports at the level of the product (and not total exports) is at play. Change in exports per product (ΔEPP) is a measure of percentage rise in average exports per product

TABLE 4. Product Innovation and Tariffs

Product Innovation Indicator		(a) Coef. (Std. Err.)	(b) Coef. (Std. Err.)	(c) Coef. (Std. Err.)	(d) Coef. (Std. Err.)	(e) Coef. (Std. Err.)	(f) Coef. (Std. Err.)
Fall in Thai tariff Δt		-0.316	$-0.343^{\dagger}$	-0.316	-0.315	-31.409^{*}	$-0.927^{\dagger}$
		(0.219)	(0.198)	(0.219)	(0.270)	(13.205)	(0.473)
Export Share $ES \cdot \Delta t$		0.095	0.137	0.095	0.004	$31.800^{\dagger}$	0.912^{*}
		(0.100)	(0.144)	(0.100)	(0.068)	(17.084)	(0.377)
Brand$\cdot \Delta t$	($\beta_3 > 0$)	0.885^{**}	0.954^{**}	0.887^{*}	0.886^{*}	$33.648^{\dagger}$	1.587^{*}
		(0.343)	(0.334)	(0.345)	(0.373)	(17.654)	(0.753)
Brand$\cdot ES \cdot \Delta t$	($\beta_4 < 0$)	-0.416^{*}	$-0.460^{\dagger}$	-0.415^{*}	$-0.326^{\dagger}$	-56.675^{*}	-2.084^{**}
		(0.186)	(0.255)	(0.186)	(0.173)	(23.322)	(0.770)
Sales			0.058				
			(0.070)				
Permanent workers			0.109				
			(0.139)				
Unskilled production workers			-0.084				
			(0.082)				
Multiple plants in industry			0.030				
			(0.072)				
Initial product range			0.160				
			(0.160)				
Fall in import duty on Intermed.				-4.180			
				(105.292)			
Fall in import duty on K-goods					0.019		
					(0.055)		
ES, Brand$\cdot ES$		yes	yes	yes	yes	yes	yes
Brand-Sector dummies		yes	yes	yes	yes	yes	yes
N		415	413	415	399	426	426
Log-likelihood/R^2		-255.33	-250.109	-255.329	-244.669	0.09	0.102

Notes: **, *and †denote 1, 5 and 10 per cent significance levels. In Columns a to d, the LHS variable is 1 if the firm increased its product range in 2005-6 and 0 otherwise. The LHS variable is Rise in Number of Design workers (D_6/D_2) in Column e and Number of Design workers during 2006 (D_6) in Column f.

from 2002 to 2006.[20] Following Lileeva and Trefler (2010), I estimate an instrumental variables regression:

$$\Delta\omega_{jn} = \beta_{\omega}\Delta EPP_{jn} + \zeta_{\omega}Z_j + \varepsilon^{\omega}_{jn} \qquad \Delta EPP_{jn} = \beta_{t\omega}\Delta t_n + \zeta_t Z_j + \varepsilon^{t}_{jn} \tag{4.3}$$

where Z_j is a vector of controls including initial process characteristics and sector dummies (as in Branstetter 2006 and Lileeva and Trefler). Rise in exports per product from 2002 to 2006 increases process innovation so $\beta_{\omega} > 0$. Exports per product fall after a Thai tariff cut so $\beta_{t\omega} < 0$. As pointed out by Lileeva and Trefler, this approach identifies process innovation from exporting

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

for firms whose exports per product responded to tariff changes. Column (a) of Table 5 shows the instrumental variable probit results for Equation 4.3. As expected, a home tariff reduction is negatively related to exports per product ($\beta_{t\omega} < 0$). Instrumenting with tariff reductions, I find higher exports per product are associated with more process innovation ($\beta_{\omega} > 0$) implying a role for economies of scale through trade.

TABLE 5. Process and Product Innovation, Exporting and Tariffs

Process Innovation Indicator	(a) Coef. (Std. Err.)	Product Innovation Indicator	(b) Coef. (Std. Err.)
Rise in Export Per Product ($\beta_{\omega} > 0$)	0.029*	Rise in Export Share ($\beta_h < 0$)	-1.676*
	(0.013)		(0.773)
Initial firm characteristics	yes	Initial firm characteristics	yes
Sector dummies	yes	Sector dummies	yes
First-Stage: Rise in Export Per Product		First-stage: Rise in Export Share	
Fall in Thai tariff Δt ($\beta_{t\omega} < 0$)	-9.939**	Fall in Thai tariff ($\beta_{th} < 0$)	-0.206**
	(3.423)		(0.055)
N	399		374
Log-likelihood/R^2	-7558.849		-282.555

Notes: **, *and †denote 1, 5 and 10 per cent significance levels. In Column a, the LHS variable is 1 if an establishment "Introduced new technology that has substantially changed the way the main product is produced" in 2005-2006 and 0 otherwise. In Column b, the LHS variable is 1 if the firm increased its product range and 0 otherwise. RHS variables include initial values for sales, permanent workers, unskilled workers, indicator for multiple plants in same industry, indicator for worker training program and percentage of profits reinvested. Column a also includes initial investments in new M&E, indicator for capacity increase while Column b includes initial product range, indicator for plans for new products and fall in import duties. Results for process innovation are similar after controlling for change in domestic sales per product.

4.4.4. *Change in Export Orientation and Product Innovation.* I test whether firms that were induced to lower their export shares ($d\theta/dt > 0$) due to Thai tariff cuts engage in lower product innovation ($dh/d\theta < 0$). A key theoretical finding is firms that suffer a relative fall in their market size are unable to overcome the rise in competition and engage in less product innovation. Home tariff cuts lower export orientation $d\theta/dt \geq 0$ which in turn increases product innovation as firms substitute away from quantity per product towards expansion of product range. Consequently, product innovation for firm j in industry n is estimated as

$$\Delta h_{jn} = \beta_h \Delta ES_{jn} + \zeta_h Z_j + \varepsilon^h_{jn} \qquad \Delta ES_{jn} = \beta_{th} \Delta t_n + \zeta_t Z_j + \varepsilon^t_{jn} \tag{4.4}$$

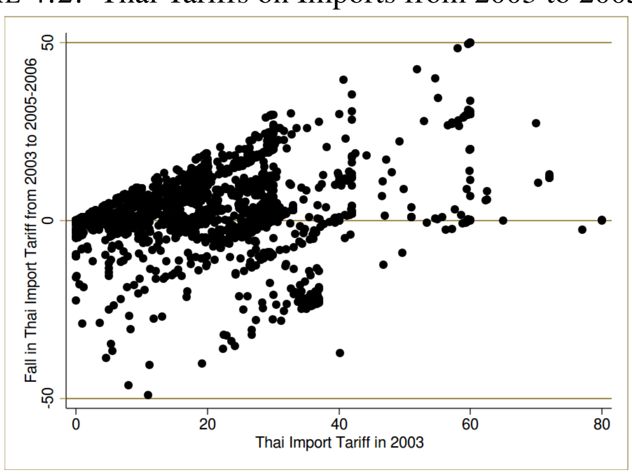
where $\Delta ES = ES_6 - ES_2$ is the rise in export share between 2002 and 2006. The expected signs are $\beta_h < 0$ and $\beta_{th} < 0$. Equation 4.4 is estimated as an instrumental variable probit regression in Column (b) of Table 5. As expected, firms that were induced to lower their export share due to Thai tariff cuts are more likely to engage in product innovation.

4.5. **Empirical Concerns.** I address key empirical concerns with the estimation of product and process innovation. The empirical identification of the effect of trade policy on innovation is based on differential reductions in Thai tariffs across 4-digit ISIC industries. This policy change has unique features that make it likely to be exogenous with respect to the outcomes analyzed, innovation and changes in export status of Thai firms between 2002 and 2005-2006. I discuss issues of reverse causality of trade policy and omitted variables in turn.

4.5.1. *Reverse Causality of Trade Policy.* The tariff changes were highly unanticipated and motivated by foreign policy considerations. With a landslide election victory, Prime Minister Thakshin Shinawatra's government geared policy towards establishing Thailand as a strong player in regional politics. As Sally (2007) notes, "Foreign-policy aspirations loom large" and the main drivers of trade policy changes were the Prime Minister's Office and the Ministry of Foreign Affairs, rather than the Ministry of Commerce and Industry. Decision-making process in PM Shinawatra's government was highly centralized with little involvement from groups outside the government. Therefore, the Thai tariff changes are unlikely to be driven by pressures from firms based on their innovation potential.

The Thai government initially indicated it would protect domestic industry (Sally 2007, Phongpaichit 2008). But most industries experienced tariff cuts rather than protection. Changes in applied rates were highly unpredictable (The WTO 2007). As found by Topalova and Khandelwal (forthcoming) for India, Thai tariff cuts reflect rationalization with high tariff industries showing larger declines as illustrated in Figure 4.2 (derived from 6-digit HS code import tariffs of UNCTAD TRAINS). These features suggest lack of innovation-specific targeting by policymakers and conforms to policy observations of the lack of political deliberations on trade policy. From an empirical standpoint, it is important that the government did not target industries on the basis of innovation activity; I will revisit this point in the omitted variables and placebo analysis.

FIGURE 4.2. Thai Tariffs on Imports from 2003 to 2005-2006



4.5.2. *Omitted Variables.* A related concern is that estimates for the effects of trade policy on innovation may be driven by other factors that are not included in the current analysis. This could imply endogeneity of trade policy which would bias the estimates. My estimation is based on cross-industry variation (at the 4-digit ISIC level) so a key concern is industry-level differences arising from factors other than Thai tariff changes.

To address this concern, I include sector dummies (2-digit ISIC roughly) to control for other sectoral differences in innovation. At the industry level, I control for import duty changes between 2002 and 2006 for each 4-digit ISIC industry and find that key results regarding tariff changes and innovation are unchanged. A fall in import duty on capital goods has the expected positive sign for process innovation as shown in Column (d) of Table 3. Following Amiti and Konings (2007) and Goldberg et al. (2009), I control for import duty reductions on intermediate goods in Column (c) of Table 4. The estimated coefficient for fall in intermediate duties and product innovation is usually statistically insignificant. A caveat in interpreting these results is that intermediate trade was practically duty-free by 2002 so there is not much variation in import duties across industries and time. A similar caveat applies to reductions in import duties on M&E. The economic magnitude of the effect is small as M&E trade had already been substantially liberalized by 2002. It is noteworthy that changes in Thai final goods tariffs are not accompanied by other major trade or industrial policies, enabling a clear focus on the effects of final goods trade policy on innovation.

Another concern is that Thai trade policy may have been targeted based on innovation potential of industries. Innovation potential of industries is likely to be correlated with initial industry-level innovation rates and productivities (e.g. Aghion et al. 1998 and Acemoglu et al. 2006). Controlling for initial industry-level innovation rates and initial industry-level productivity does not alter the main findings for tariff cuts and innovation (omitted for brevity).[21] Similarly, including changes in foreign tariffs and tariffs of major trade partners does not alter my key findings. These tariff changes show lower variation and are mostly statistically insignificant.

To capture heterogeneity in innovation across firms, the estimating equations include firm-level exporting and branding status as explanatory variables. This may lead to biased estimates arising from omission of firm characteristics that are correlated with initial exporting and branding. Admittedly, this is a challenging issue and I build on previous work and the richness of the survey to minimize this problem. Following Bustos (2009), I include firm size variables and workforce characteristics as RHS variables. Tables 3 and 4 show the robustness of key results for Thai tariff changes and innovation after including these RHS variables.

As in Bustos and Lileeva and Trefler, I am limited in terms of productivity estimation. However, I am able to use rich variables which are relevant for innovation. A noteworthy finding is the role of international technology transfer in productivity improvement. I include indicators for

[21] All unreported results are available upon request.

whether the firm learned new technology from a client MNC and whether it participated in licensing/training/quality certification programs provided by a client MNC. Firms that learn new technologies from MNCs are more likely to implement process innovation in Column (c) of Table 3. However, mere participation in MNC programs is not positively correlated with process innovation. Results are also robust to inclusion of initial new technology and products, worker training and plans for new investments in technology and products (as in Lileeva and Trefler).

4.5.3. *Placebo Analysis.* Following Bernard et al. (2006), I conduct a placebo test to further address concerns of endogeneity of trade policy arising from reverse causality and omitted variables. Using measures of *initial* process and product innovation before the tariff changes, I show that Thai tariff changes are not simply reinforcing pre-existing trends in innovation and indeed induce changes in firm innovation behavior. Equations (4.1) and (4.2) are estimated using product and process innovation from the first round of the survey. I use the same process innovation indicator as in the baseline estimation of Column (a) in Table 3. For product innovation, I do not have the product innovation indicator used in the baseline estimation of Column (a) in Table 4. Consequently, I use a different measure of product innovation. The first survey asked firms whether they planned to introduce any new designs or products in the next two years.

TABLE 6. Thai Tariffs and *Initial* Process and Product Innovation

Initial Process innovation	(a) Coef. (Std. Err.)	*Initial* Product innovation	(b) Coef. (Std. Err.)
Fall in Thai Tariff Δt	-0.338	Fall in Thai tariff Δt	-0.578
	(0.309)		(0.490)
Exporter$\cdot\Delta t$	0.254	Export Share $ES\cdot\Delta t$	-0.262
	(0.490)		(0.276)
		Brand$\cdot\Delta t$	0.271
			(0.615)
		Brand$\cdot ES\cdot\Delta t$	0.676
			(0.467)
Exporter-Sector dummies	yes	Brand-Sector dummies	yes
N	423		424
Log-likelihood	-266.501		-261.083

Notes: **, *and †denote 1, 5 and 10 per cent significance levels. The LHS variable in Column a is 1 if an establishment "Introduced new technology that has substantially changed the way the main product is produced" in 2003-2004 and 0 otherwise. The LHS variable in Column b is 1 if the establishment reported in 2003 that it was "planning to introduce new designs/products in the next 2 years (2004-2005)" and 0 otherwise.

Table 6 shows the lack of response in innovation measured by the process innovation indicator and the planned introduction of new products in 2003. I find that each coefficient on tariff change is statistically indistinguishable from zero. Tariff changes are not systematically related to initial innovation. On the other hand, innovation variables for 2005-6 show the predicted relationship with tariff changes in the baseline estimation. This points to the unanticipated nature of Thai tariff changes and the role of trade policy in altering innovation behavior of firms.

4.6. **Discussion.** The theory shows home tariff cuts impact innovation of home firms through an indirect equilibrium effect, rather than a direct cost effect. Consequently, the innovation responses may be statistically significant but economically subtle. In the remainder of this Section, I briefly summarize the economic magnitude of Thai innovation responses. Then I consider validity checks for the equilibrium effects by examining the responses of Malaysian incumbents to Thai tariff cuts and the relevance of intra-brand cannibalization.

4.6.1. *Quantitative Summary.* Tariff changes are quantitatively important in explaining variation in each type of innovation. On average, I find a 1 per cent Thai tariff cut lowers process innovation by 0.19 percentage points, relative to non-exporters. For reference, mean of the process innovation indicator is 0.50 for all Thai incumbents, 0.44 for non-exporters and 0.53 for exporters. Therefore, the differential response from an average 40 per cent Thai tariff cut is 16 per cent of the mean $((0.19/50) \times 0.4)$. This is economically significant in light of the fact that the difference in means of process innovation for exporters and non-exporters is 0.09 and the documented difference in total factor productivity of exporters and non-exporters is 3 per cent (Bernard et al. 2007 for US firms).

For product innovation, I find a 1 per cent Thai tariff cut increases product innovation of branded non-exporters by 0.31 percentage points, relative to unbranded non-exporters. For reference, mean of the product innovation indicator is 0.36 implying the differential response from the average 40 per cent Thai tariff cut is 34 per cent of the mean. Every 1 per cent share of sales exported implies a reduction in product innovation of 0.15 percentage points for branded exporters, relative to unbranded exporters. These results show that the theoretical relationship between tariff changes and innovation implied by Proposition 4 is empirically relevant. 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).[22]

4.6.2. *Malaysian Response to Thai Tariff Changes.* Profit shifting to foreign firms is a key theoretical channel through which unilateral home tariff cuts affect innovation of home firms. Consequently, I examine whether Malaysian firms responded to Thai tariff cuts in ways predicted by the theory.

Detailed firm-level data containing exporting and innovation is rare so I focus on Malaysia for which comparable establishment-level data is available for a randomly sampled cross-section of establishments in 2005-6.[23] Malaysia, Thailand and Indonesia together form the ASEAN growth

[22] Quantitative interpretations are based on specifications in Column (a) of Tables 3 and 4 under OLS.

[23] A caveat is in order. Data is available for only one round so sales and innovation variables are based on establishment-level data from the 2007 round of the Malaysian PICS. Exporting is based on the history for 2004 while the branding question was asked in 2006.

triangle which has a strong emphasis on intra-triangle trade. Given the size similarity of these countries, it is reasonable to expect Thai tariff cuts to impact decisions of Malaysian firms.

A Thai tariff cut lowers the market size available to Thai exporters but increases the market size available to Malaysian exporters. I examine the sales and innovation implications of this rise in market size for Malaysian firms. First, I examine whether Malaysian exporters gained market size in response to Thai tariff cuts. Column (a) of Table 7 shows that exporters show a significantly higher sales response to Thai tariff cuts, compared to non-exporters. These results are robust to controlling for other changes during the period (e.g. import duties and tax rates).

TABLE 7. Malaysian Sales, Exporting and Thai Tariffs

Rise in Malay Sales in 2004-6 (mn RM)	(a) Coef. (Std. Err.)	Process Innovation	(b) Coef. (Std. Err.)	Product Innovation	(c) Coef. (Std. Err.)
Fall in Thai tariff Δt	-0.873	Fall in Thai tariff Δt	-0.296	Fall in Thai tariff Δt	-0.113
	(2.390)		(0.205)		(0.142)
Exporter$\cdot\Delta t$ ($\beta_s^* > 0$)	39.578**	Exporter$\cdot\Delta t$ ($\beta_2^* > 0$)	0.648*	Export Share $ES \cdot \Delta t$	-0.050
	(14.599)		(0.292)		(0.213)
		Import duty fall: M&E	0.046**	Brand$\cdot\Delta t$ ($\beta_3^* < 0$)	-0.207†
			(0.015)		(0.105)
				Brand$\cdot ES \cdot \Delta t$ ($\beta_4^* > 0$)	0.231*
					(0.097)
N	1014		1001		1020
R^2/Log-likelihood	0.026		-547.209		0.097

Notes: **, *and †denote 1, 5 and 10 per cent significance levels. The LHS variable in Column a is Rise in Sales of Malaysian establishments (in million Malaysian Ringitt) from 2004 to 2006. Exporter is 1 if export sales are positive in 2004 and 0 otherwise. The RHS in Column a includes exporter-sector dummies where a Sector refers to a 2-digit ISIC code. The LHS variable in Column b is 1 if an establishment "Introduced new technology that has substantially changed the way the main product is produced" in 2005-2006 and 0 otherwise. Fall in import duty refers to the percentage fall from 2004 to 2006. The RHS in Column b includes exporter-sector dummies. The LHS variable in Column c is the Number of Design workers during 2006 (log(1+D_6)). Export share is the fraction of exports in total sales during 2004. Brand is 1 for firms making branded products in 2006 and 0 otherwise. The RHS in Column c includes sector dummies.

Second, I examine whether innovation patterns of Malaysian incumbents are consistent with the theory. From Section 3, an increase in market size from Thai tariff cuts is expected to increase process innovation of Malaysian exporters. Column (b) of Table 7 confirms that Malaysian exporters respond to Thai tariff cuts by undertaking greater process innovation than non-exporters. Regarding product innovation, I expect to find an increase in product innovation among large exporters and a drop among small exporters and non-exporters. Large exporters are able to overcome tougher competition from a bigger market by capturing a higher share of the Thai market. They can absorb higher cannibalization from product innovation and expand their product range. Small exporters and non-exporters are unable to overcome the loss in profits from tougher market conditions in

Malaysia. They cut back on product lines to ease intra-brand cannibalization. As expected, Column (c) of Table 7 shows higher investment in product innovation at high levels of export shares and lower investment at low levels of export shares among branded incumbents. Results are robust to firm characteristics (e.g. initial sales and size).

Comparing with Thai incumbents, innovation responses of Malaysian incumbents are smaller in magnitude. However, a direct comparison of magnitudes is less meaningful due to large differences in overall innovation levels. Average process innovation is 0.25 in Malaysia and 0.50 in Thailand while average design employment is 1 in Malaysia and 1.5 in Thailand.

4.6.3. *Intra-brand Cannibalization.* A remaining question is whether intra-brand cannibalization is at work. 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.

In an online 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 et al. (2008), prices are instrumented with supply-side variables (firm-specific productivity). I use both observable productivity measures and unobservable productivity measures (TFPs estimated using factor rewards as instruments and Ackerberg et al. 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 0.32 among multiproduct firms. This estimate is similar to Broda and Weinstein (2010). Allowing the intercept of demand for other products to vary by branding status, I find that the negative relation between demand for the main product and other products of the establishment is driven by firms selling branded products. Though the usual caveats of demand estimation apply, the results provide promising evidence in favor of the role of intra-brand demand linkages in firm decisions.

5. Conclusion

Firms face competing needs to invest in product and process innovation. This paper introduces a framework to study the impact of market forces on these investments. In this framework, intra-brand cannibalization distinguishes product and process innovation. A firm's new product cannibalizes its old products more than products of other firms. This has consequences for the impact of competition on innovation strategies of firms. Focusing on trade policy, I provide new results for the impact of trade on market forces and firm innovation.

Opening to 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. These two forces of market expansion and tougher competition have opposite effects on innovation. Market expansion results in greater process innovation through economies of scale. Tougher competition and firm adjustment to cannibalization result 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 expand output per product to supply to the foreign market.

A unilateral home tariff liberalization induces the opposite firm responses because it shifts profits away from home firms. I provide support for these firm responses with innovation data from Thailand's manufacturing sector. Between 2003-2006, Thai manufacturing industries experienced unilateral home tariff changes. In industries with larger tariff cuts, I find Thai exporters experienced a fall in export scale and lowered process innovation. Branded Thai incumbents adapted to the tariff changes by altering product innovation as predicted by the theory. Incumbents with low export shares increased product innovation while incumbents with high export shares lowered product innovation. As expected, Malaysian exporters gained at the expense of Thai exporters and those with the largest export shares engaged in more product and process innovation.

These findings reveal how trade policy affects innovation. Tybout and Westbrook (1995) propose that the bulk of production gains accrue within firms through factors such as process rationalization, product expansion, capacity utilization and changes in lengths of production runs. They conclude that "much remains to be done in documenting the relative importance of these effects." Empirical work has begun to address the role of trade in influencing these factors. Building on these empirical insights, I characterize how firms innovate and how their responses shape production gains from trade liberalization. The theoretical and empirical issues involved in unbundling innovation are formidable. This paper conceptualizes some of the issues but several questions merit further investigation. Fortunately, new plant-level surveys on innovation activities are increasingly becoming available. Future empirical and theoretical work based on longer panels across countries can provide more insight into dynamics, cross-industry differences and cross-country determinants in fostering innovation.[24]

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[24] See Costantini and Melitz (2008) and Ederington and McCalman (2008) for dynamic aspects and Eckel et al. (2009) for cross-industry differences.

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APPENDIX A. APPENDIX

A.1. **Assumptions.** I assume $\alpha > c + 2(\gamma f/L)^{1/2}, 2\eta^{1/2}$ to ensure consumption of both homogeneous and differentiated goods in equilibrium, as in Melitz and Ottaviano (2008). For a strictly concave firm problem, I need to ensure that quantity and process choices are such that the drop in own marginal revenue from higher quantity relative to the cost savings per unit from a better process is greater than the cost savings relative to the rate of decline in cost savings with a better process. For this purpose, I assume $\delta/L > c'(\omega)^2[a - c(\omega)]/2c''(\omega)[r_\omega \omega + r_h]$ for all $\omega > 0$. For $c(\omega) = c - c\omega^{1/2}$, a sufficient condition in terms of primitives is

$$\delta/L > c\left[r_h^{1/2}(\delta/L - c^2/4r_\omega)^{1/2} + (\gamma f/L)^{1/2} + c/2\right]/2r_\omega^{1/2} r_h^{1/2}$$

Positive unit costs after innovation are ensured by $\delta/L > c^2(r_\omega + r_h)/4r_\omega^2$ which is consistent with the above concavity condition.

A.2. **Symmetric Firms.** Proof of Proposition **3**. Follows from the relation between θ and trade liberalization and industry demand conditions and trade liberalization. As in Nocke and Yeaple (2005), I consider tariff changes evaluated in an interior equilibrium starting from $t = t^* > 0$. However, the results hold more generally as long as the export to domestic production ratios are less than 1. 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:

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

and the analogous expressions for the foreign firms. Along with the FOCs, Equation A.1 provide six equations in six unknowns a, a^*, θ, θ^*, y, y^*, h and h^*. Totally differentiating industry-wide demand conditions (Equation A.1), $d\theta/dt^* < 0$ and $d\theta^*/dt^* > 0$. A direct corollary is that a bilateral trade liberalization yields $d\theta/dt < 0$. Full details are given in an online Appendix.

A.3. **Heterogeneous Firms.** With firm heterogeneity, firm choices are determined in a manner similar to Section 2. 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 $s_{x\omega}(c) \equiv (1+\theta^2_{x\omega}(c))/(1+\theta_{x\omega}(c))^2$ 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. It may be shown that profit is $\Pi_{x\omega}(c) = \frac{L}{4\gamma}[(1+\theta^2_{x\omega})^{1/2}(a - c + 1_{\omega>0}\omega(c)) - 2(\delta/L)y_{00}(1 + r_\omega/r_h)^{1/2}]^2$. I focus on characterizing firm responses in a to small changes in t and t^*at a given interior equilibrium, starting from $t = t^* > 0$.

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

Proof. 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. Assuming $g(c)$ is such that the set of producers is convex, the free entry condition gives

$$\sum_i \sum_j \int_{\underline{c}_{i,j}}^{\bar{c}_{i,j}} \partial\Pi_i(c)g(c)/\partial t^* dc = 0 \tag{A.2}$$

Differentiating the profit functions with respect to t^*, $\Pi'_{x\omega}(t^*) = (hy)_{x\omega}[da/dt^* + \theta_{x\omega}(da^*/dt^* - 1)]/(1+\theta_{x\omega})$. 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 $\tilde{\theta} \equiv B/A$ is the ratio of export production to domestic production. Substituting in Equation A.2, changes in aggregate home and foreign market conditions are $da/dt^* = \tilde{\theta}/(1 - \tilde{\theta}\tilde{\theta}^*) > 0$ and $da^*/dt^* = -\tilde{\theta}^* da/dt^* < 0$. Note that a bilateral reduction in tariffs lowers a as $da/dt = \tilde{\theta}(1-\tilde{\theta}^*)/(1-\tilde{\theta}\tilde{\theta}^*) > 0$.

Proof of Proposition **4**. If a firm is 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 $\omega(c_{00,01}) = 2(\delta/L)^{1/2} r_h^{1/2}[(1 + r_\omega/r_h)^{1/2} - 1]$. 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, process innovation weakly increases among new exporters. The argument for bilateral liberalization is similar except $da^*/dt = da/dt$. 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 is $dh_i/dt^* = (h_i/2\Pi_i)d\Pi_i/dt^*$ 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. **Data Sources and Definitions.**

(1) Tariffs. 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. In order to avoid zero denominators and sensitivity from low initial tariffs, percentage change in tariffs is calculated at the midpoint following Allen and Lerner (1934). Specifically, $\Delta t = (t_2 - t_{56})/0.5(t_2 + t_{56})$ where the subscript denotes 2002 and 2005-2006. Thai tariffs do not contain zeros but foreign tariffs do contain zeros.

(2) Product and process variables are explained in the main text. For the product innovation indicator, 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. All remaining variables are taken directly from the survey. Due to zeros, the following scaling is applied. New M&E in 2005-2006 is $ME_{56} \equiv \ln(1 + me_{56})$. Rise in New M&E is $ME_6/ME_2 \equiv (1+me_6)/(1+me_2)$ where lowercase letters denote reported values. Design workers in 2006 refer to $D_6 \equiv \ln(.01 + d_6)$ and Rise in Design workers is D_6/D_2.

(3) Export per product. It 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 $EPP = (r_1^x + r_2^x + r_3^x)/3$ where

revenue is in million Bahts. Change in exports per product (ΔEPP) refers to changes from 2002 to 2006. I define ΔExports per product (ΔEPP) as $(1+EPP_6)/(1+EPP_2)$ where the scaling is applied to account for zero exports in 2002.

(4) Firm characteristics. Initial sales, permanent workers and unskilled production workers refer to 2002 values scaled as $\ln(1+x)$.

(5) Import duty on K-goods. Fall in import duty on capital goods refers to fall in average import duty paid on the "most recent purchase" of imported M&E reported by establishments in each 4-digit ISIC industry between 2002 and 2006.

(6) Import duty on Intermediates. Fall in import duty on intermediates refers to fall in average import duty paid on "materials and components" reported by the plant in each 4-digit ISIC industry between 2002 and 2006. For industries that do not purchase any imported intermediates, the value is coded as zero but results are robust to including a separate dummy variable for these industries.