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International Trade and Firm's Technological Choice

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Preliminary

Abstract

This paper analyzes the impact of international trade on a firm′s technological choice. Specifically, we examine how income and technological levels of export destination countries affect exporting firms′ relative incentives between product innovation and process innovation. Based on an illustrative model of vertical product differentiation, this paper suggests that bilateral trade between countries of different income levels tends to weaken the incentive for product innovation for both countries, relative to the autarky case. In addition, other things being equal, trade with countries whose income levels are relatively higher further reduces exporters' incentive for product innovation, unless technology gap between trade partners is sufficiently large. Using the firm-level data for Korean manufacturing for the period of 2005-07, we find that there exists an inverted U-shaped relationship between trading partner′s income level and the R&D expenditure share on new product innovation. Our estimation results indicate that the relative incentive to invest in new product innovation tends to increase until the income level of the major trading partner reaches at 5,260 US dollars, then it decreases afterward.

JEL Classification: F12, O33, L1
Keywords: Product Innovation, Process Innovation, International Trade, Vertical Product Differentiation

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I. Introduction

Technology investment by profit-seeking firms aims not only to increase production efficiency (process innovation), but also to improve the quality of products they produce (product innovation)2. Different market environments would drive individual firms to engage in distinct modes of technological investments (Boone, 2000; Bonanno and Haworth, 1998).

While the existing theoretical models of international trade largely emphasize technology as a key determinant of trade patterns and of trade-induced welfare change, most of them incorporate only a unidimensional aspect of technological innovation in their models; either process innovation or product innovation but not both. Furthermore, in these models technological innovation itself is often assumed to be a random process determined by nature; i.e. exogenous shocks to productivity. This assumption is quite in contrast to the fact that firms make an endogenous decision for their own technological investment.

This paper attempts to fill this gap by explicitly considering firm′s endogenous decision on technological investment under an international trade setting, both theoretically and empirically. We first present a simple illustrative model that accounts for firms′ decisions whether to direct their R&D expenditure towards product innovation or towards process innovation. We focus on the case in which the main burden of quality improvement falls on R&D costs.[3] Our analysis builds on the model of vertical product differentiation, which is inspired by Shaked and Sutton (1982).

Specifically we explore how income and technological levels of export destination countries affect exporting firms′ relative incentives between product innovation and process innovation. This paper suggests that bilateral trade between countries of different income and technology levels tends to weaken the incentive for product innovation for both countries, relative to the autarky case. In addition, other things being equal, trade with countries whose income levels are relatively higher further reduces exporting firms′ incentive for product innovation.

Using the firm-level data for Korean manufacturing for the period of 2005-

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2 According to the Oslo manual, process innovation is defined as the implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software. On the other hand, product innovation is the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses.

3 Notable examples in the real world are computers, automobiles and telecommunications among others.

07, this paper confirms that the investment share on product innovation is slightly lower for exporting firms compared to non-exporting counterparts. More importantly, we find an inverted U-shaped relationship between trading partner′s income level and the R&D expenditure share on new product innovation.

The structure of this paper is as follows. In Section II, we introduce a literature survey on the existing related studies. The basic model and its outcomes both under the autarky and trade regimes are described in section III. Section IV presents the results of our empirical exercise on the impact of international trade on firm's technological choice. Some model implications and concluding remarks are discussed in Section V.

II. Literature Survey

As aforementioned, typical theoretical models of international trade assume that innovation is an exogenous process, or simply a by-product of investment in machinery and equipment (Eaton, 2002; Melitz, 2003). In these models, randomly-drawn innovation leads to improve firm-level total factor productivity (TFP hereafter). By definition, TFP basically measures change in productive efficiency and so reflects well the effects of cost-reducing innovation. On the other hand, it captures only imperfectly those of changes in the quality of goods and services available to consumers (Hulten, 2000).

Under such assumption, an extensive body of empirical studies suggests a positive effect of innovation on exports at the firm- or plant-level. For example, Bernard and Jensen (1999), among many others, provides convincing evidence that the most productive firms self-select into exporting activities and the others serve only domestic markets..

On the other hand, research on the innovation-export nexus, which explicitly consider an endogenous determination in different types of innovations - process innovation and product innovation, for example -, has been relatively scarce so far.

Along this strand of research, using a panel of Spanish manufacturing firms for the period 1990-1999, Cassiman and Martinez-Ros (2007) empirically examine the relative importance between product innovation and process innovation on the probability of export market entry. They find that product innovation is a more important driver of exports, especially for small non-exporting firms.

In a similar vein, Becker and Egger (2013) investigate the role of product versus process innovation on export propensity at the firm level through a double treatment approach. Their empirical results also point to the importance of product innovation for export decision. While firms that engage in both process and product innovation reveal a higher probability to export than others, product innovation seems to be a more determinant in the exporting behavior of a firm.

Finally, Van Beveren and Vandenbussche (2010) also test the relationship between firm-level innovation and export entry, by applying an instrumental variable estimation to the data from an Belgium innovation survey. In contrast to Becker and Egger (2013), they find little evidence that product and process innovations stimulate entry into the export market. Their results suggest that firms are self-selecting into innovation in anticipation of their entry into export markets through trade liberalization.

Compared to the existing literature, our paper is distinctive for the following aspects; first of all, similar to Becker and Egger (2013), for example, we explicitly incorporate different roles of product and process innovations in relation with international trade. Second, while most of the aforementioned studies focus on the causal impact of innovation on exports, we hypothesize an opposite causal link from trade participation to firm's decision between process and product innovations. Finally, we present a simple illustrative model of vertical product differentiation to provide a theoretical foundation on the export-innovation nexus.

III. The Model

3.1. Basic Model Setting

Assume that there is a continuum of consumers identical in tastes but differing in income. Incomes in an economy are uniformly distributed over the interval of $[\overline{\mathrm{m}}, \underline{\mathrm{m}}]$, where $0 < m < \overline{\mathrm{m}}$ with a continuous positive density K. Each consumer purchases either at most one indivisible unit of the quality-differentiated good that offers the greatest utility, or else no quality good at all. N distinct quality goods are available for consumers and we label these in increasing order of quality which is denoted by q i.e. $\mathrm{q}_1 < \mathrm{q}_2 < \cdots, < \mathrm{q}_\mathrm{n}$.

Consumer preferences are represented by the following utility function:

$$U(m, q_k) = u(q_k)m - p_k \qquad (3.1)$$

where m is an individual consumer′s income and p_k is the price of one unit of the differentiated good. $\mathrm{u}(\mathrm{q}_\mathrm{k})$ is a sub-utility function from consuming a good of quality of k, a strictly increasing function with respect to k.

Suppose for a moment that there are two types of differentiated goods $= 1, 2$: For expositional convenience, denote these by ″low″ quality (L) and ″high″ quality (H), respectively. Based on the utility function (3.1), we can define the income level, denoted by $\mathrm{m}^*_{\mathrm{H,L}}$, such that a consumer with income m^* is indifferent between consuming a quality q_L at the price of p_L and consuming q_H at the price level of p_H:

$$m^*_{H,L} = \frac{p_H - p_L}{u(q_H) - u(q_L)} \qquad (3.2)$$

A household strictly prefers the high quality product only if its income is greater than $m^*_{H,L}$. Otherwise, it will be better off buying the low quality good, or not purchasing the differentiated good at all. Letting $\beta_{H,L} = 1/[u(q_H) - u(q_L)]$ we rewrite (3.2) as $m^*_{H,L} = \beta_{H,L}(p_H - p_L)$ Then, the aggregate market demand function for each quality can be represented by

$$x_H(q,p,m,K) = \left(\overline{m} - m^*_{H,L}\right)K = \left[\overline{m} - \beta_{H,L}(p_H - p_L)\right]K \qquad (3.3)$$

$$x_L(q,p,m,K) = \left(m^*_{H,L} - m^*_{L,0}\right)K = \left[\beta_{H,L}(p_H - p_L) - \beta_{L,0}p_L\right]K \qquad (3.4)$$

where $m^*_{L,0}$ is the income level for which the corresponding consumer is indifferent between consuming nothing and consuming the low-quality product. This paper focuses on the case in which the market is not fully covered, i.e. $m^*_{L,0} > \underline{m}$, to avoid a corner solution.[4] Therefore, there exist consumers in the lowest band of income level who do not purchase the differentiated goods. The utility for those consumers is represented by $U(m, 0) = u_0 m$ where $u_0 > 0$.

3.2. The Autarky Regime

3.2.1. Monopoly case

We examine here the factors that would be important in a firm′s decision whether to direct their R&D expenditure towards product innovation or towards process innovation. We start by considering a monopoly case under the autarky. At the beginning of a time period, a monopolist chooses exclusively either to invest in product innovation to market a new quality product or process innovation to reduce the production costs of a quality of good currently available in the market. Each innovation requires a fixed level of R&D costs, *F*. The degree of each quality improvement or cost reduction is exogenously determined, and it is perfectly foreseeable to the firm. For simplicity, we assume that all producible goods have the same unit cost, regardless of quality level, i.e. $c_k = c$ for all k. The monopolist maximizes expected profits by producing a single quality of good. The sales of products are made at the end of the period.

Suppose that the quality currently available in the market is q_L. If the

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[4] In general, the market is fully covered if and only if $p_L \leq min\left\{\frac{m^*_{L,0}}{\beta_{L,0}}, \frac{\beta_{H,L}}{\beta_{H,L}-1}p_H - \frac{m^*_{H,L}}{\beta_{H,L}-1}\right\}$

monopolist decides to produce q_H through product innovation, then the firm's profit function, π_M^q is represented by

$$max\,\pi_m^q = (p_H - c)x_H - F \qquad (3.5)$$

where $x_H = [\overline{m} - \beta_{H,0}p_H]K$ and $\beta_{H,0} = 1/[u(q_H) - u_0]$. By differentiating (3.5) with respect to p_H, we have

$$\begin{aligned}\frac{\partial \pi_M^q}{\partial P_H} &= \ x_H K + (p_H - c)\frac{\partial x_H}{\partial P_H} \\ &= \ (\overline{m} - m_{H,0}^*)K - (p_H - c)\frac{\partial m_{H,0}^*}{\partial P_H}K \\ &= \ (\overline{m} - \beta_{H,0}p_H)K - (p_H - c)\beta_{H,0}K = 0\end{aligned}$$

and the solutions to this profit maximization problem are as follows:[5]

$$x_M^q = \frac{(\overline{m}-\beta_{H,0}c)K}{2}, \ \ p_M^q = \frac{\overline{m}-\beta_{H,0}c}{2\beta_{H,0}}\, and\ \ \pi_M^q = \frac{(\overline{m}-\beta_{H,0}c)^2K}{4\beta_{H,0}} - F \qquad (3.6)$$

On the other hand, if the firm is undertaking a cost-reducing innovation on the production of the existing quality good, then the profit function, π_M^c is

$$max\,\pi_M^c = \big(p_L - (c_L - \Delta c_L)\big)x_L - F \qquad (3.7)$$

where $x_L = [\overline{m} - \beta_{L,0}p_L]$ and Δc_L is the amount of cost reduction induced by process innovation. At the equilibrium, we have

$$x_M^c = \frac{\big(\overline{m} - \beta_{L,0}(c - \Delta c_L)\big)K}{2}, \qquad p_M^c = \frac{\overline{m} - \beta_{L,0}(c - \Delta c_L)}{2\beta_{L,0}}$$

$$and\ \ \pi_M^c = \frac{\big(\overline{m}-\beta_{L,0}(c-\Delta c_L)\big)^2K}{4\beta_{L,0}} - F \qquad (3.8)$$

When $\pi_M^q > \pi_M^c$, the firm would prefer product innovation. If $\pi_M^q < \pi_M^c$, it invests in process innovation. Finally, the firm is indifferent between product and process innovation if $\pi_M^q = \pi_M^c$Therefore, using these two profit functions, we can derive a critical level of cost reduction, denoted by Δc_L^*, for which the

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[5] The density K represents the size of an economy. Notice that an increase in K raises sales and profits of all firms, but leaves equilibrium prices unchanged.

firm is indifferent between two innovations. The following lemma characterizes the condition under which the monopolist chooses one innovation type over the other:

Lemma 1 *Suppose that* $\overline{m} > \beta_{k,0}c$ *for* $k = L, H$. *The monopolist would exclusively invest in product innovation only if cost reduction* (Δc_L) *through process innovation for the existing product is smaller than a critical level* (Δc_L^*) *of cost reduction where the firm is indifferent between two innovations s.t.* Δc_L^* *is* [6]

$$\Delta c_L^* = \frac{(\sqrt{\beta_{L,0}} - \sqrt{\beta_{H,0}})\overline{m} - (\sqrt{\beta_{L,0}}\beta_{H,0} - \sqrt{\beta_{H,0}}\beta_{L,0})c}{\sqrt{\beta_{H,0}}\beta_{L,0}} \qquad (3.9)$$

Figure 3.1 graphically explains this lemma. In the figure, the iso-profit locus of a given level of π_M^q is depicted in the (c, β) plane. Higher quality corresponds to lower β. The point O represents the profit level achievable without innovation. The firm has two choices: moving to A through developing and selling a product of higher quality through product innovation, or moving downwards to C or B through process innovation. The critical level of cost reduction where the firm is indifferent between two types of innovation is represented by Δc_L^*. Therefore, if the cost reduction through process innovation is large enough to move down to B (i.e.$\Delta c_L > \Delta c_L^*$), then this means that investing in process innovation is more profitable than product innovation. On the other hand, if $\Delta c_L < \Delta c_L^*$, then $\pi_M^q > \pi_M^c$ and consequently the firm undertakes quality improvement. Finally, if $\Delta c_L = \Delta c_L^*$ then the firm is indifferent between the two innovations.

Note that, since $\beta_{L,0} > \beta_{H,0} > 0$, we have $\frac{\partial c_L^*}{\partial \overline{m}} > 0$. We interpret this in the following ways: other things being equal, a firm in the country of relatively a higher income level has a higher incentive to undertake product innovation than others. The higher level of income implies a higher willingness to pay for quality among consumers. This provides a more attractive market environment for a firm to market a higher quality good.

Proposition 1 *Suppose that* $\overline{m} > \beta_{k,0}c$ *and* $c_k \neq c$ *for any* $k = 1, \cdots, n$. *As the consumers' income becomes higher, the monopolist's relative incentive for product innovation over process innovation also increases.*

Figure 3.2 depicts several profit loci in the (c, β) plane, differing in the value of $\overline{m}$. As shown in the figure, as $\overline{m}$ increases, more cost reduction is needed to attain the same level of profit from product innovation. Therefore, it is

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[6] If $c_L \neq c_H$, then $\Delta c_L^* = \frac{(\sqrt{\beta_{L,0}} - \sqrt{\beta_{H,0}})\overline{m} - \sqrt{\beta_{L,0}}\beta_{H,0}c_H + \sqrt{\beta_{H,0}}\beta_{L,0}c_L}{\sqrt{\beta_{H,0}}\beta_{L,0}}$. Hence, the marginal cost for producing high quality is higher the lower is Δc_L^* and the incentive to product innovation.

relatively easier to have higher profits by producing high quality rather than low quality. Finally, note also that $\frac{\partial \Delta c_L^*}{\partial \beta_{H,o}} < 0$. Other things being equal, a larger increase in utility from consuming a high quality good induces a bigger increase in Δc_L^* and thus a higher incentive for product innovation relative to process innovation.

3.2.2. Duopoly Case

This section concerns how the introduction of market competition alters the innovation incentives. Our analysis is based on a two-stage non-cooperative duopoly game. There are two firms, Firm 1 and 2, in an economy. In the first stage of the game, the two firms choose their innovation strategies, sequentially; that is, Firm 1 first makes a decision on the type of innovation that they pursue, anticipating the subsequent entry of Firm 2. After having observed Firm 1's innovation choice, Firm 2 chooses its innovation type. In the second stage, the firms compete in prices for consumers.[7]

The model is specified so that the firms' price strategies in the second stage are a Nash-Bertrand equilibrium for any set of products chosen in the first stage. The market demands are the same as those represented in (3.3) and (3.4). If two firms are undertaking the same type of innovation, price competition in the second stage leads to zero profit for each firm. This means that, at the equilibrium, the firms are undertaking different types of innovation. If Firm 1 decides to pursue product innovation, then Firm 2 would choose process innovation. Otherwise, Firm 2 would undertake product innovation.

If Firm 1 markets a new quality good, q_H then its profit function is $\pi_1^q = (p_{1,H} - c)x_{1,H} - F$ and the second firm's profit is represented by $\pi_2^c = (p_{2,L} - c + \Delta c_{2,L})x_{1,L} - F$. On the other hand, if Firm 1 chooses process innovation with the quality currently available in the market, q_L, at the first stage, then its profit function would be $\pi_1^c = (p_{1,L} - c + \Delta c_{1,L})x_{1,L} - F$, while the second firm produces a high quality and its profit function is $\pi_2^q = (p_{2,H} - c)x_{2,H} - F$. Given these profit maximization conditions, we can again derive the critical level of cost reduction that makes the innovator indifferent between

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[7] Some important comments are needed at this point. First, cooperative market equilibria also possibly happen, but we are not examining these here because they are beyond the focus of the paper. Some of the industrial organization literature exploits these cooperative equilibria in a similar set-up as here. For example, see Gabszewicz and Thisse (1982). Second, assuming the Cournot game, instead of Bertrand game, changes some of the results derived in this section. The implications we aim to show, however, are robust to the choice for the mode of competition. See Motta (1993).

product and process innovation. This critical value, along with profit functions, is presented in Appendix B. Here, we are particularly interested in the relationship between income level and the innovation incentive. Specifically, we focus on how the marginal effect of the income level on innovation incentive differs from the monopoly case, once we introduce market competition into the model. By differentiating Δc_L^* with respect to $\overline{m}$, we have

$$\frac{\partial \Delta c_L^*}{\partial \overline{m}} = \frac{\left(2\beta_{L,0}+2\beta_{H,L}-\sqrt{\beta_{H,L}}\sqrt{\beta_{H,L}+\beta_{L,0}}\right)}{\left(\beta_{H,L}+2\beta_{L,0}\right)\sqrt{\beta_{H,L}}\sqrt{\beta_{H,L}+\beta_{L,0}}} > 0 \qquad (3.10)$$

This inequality holds because $\beta_{L,0} > \beta_{H,0} > 0$, $\beta_{H,L} > 0$ and $2\beta_{L,0} + 2\beta_{H,L} > \sqrt{\beta_{H,L}}\sqrt{\beta_{H,L} + \beta_{L,0}}$. Comparing (10) with (9), we have the following:

Proposition 2 *When the consumers' income becomes higher, a firm's incentive for a firm to undertake product innovation increases more for the duopoly case than the monopoly one; i.e.* $\left.\frac{\partial \Delta c_L^*}{\partial \overline{m}}\right|_{mono} < \left.\frac{\partial \Delta c_L^*}{\partial \overline{m}}\right|_{duo.}$

Proof. See Appendix A

Recall that the burden of quality improvement falls on fixed costs and unit costs are constant regardless of product quality. Under this circumstance, a successful innovator producing a new product of high quality can charge a price at a level that the innovator would relatively easily reduce the market share of the firm producing low quality goods. Therefore, the presence of the rival firm marketing a high quality good requires a larger process innovation to maintain a certain level of profits. This makes product innovation relatively more attractive.

3.3 The Trade Regime

3.3.1. Trade Equilibrium and Pattern of Trade

In this section, we examine how bilateral trade between countries of different income and technology levels affects firms′ incentive to innovate.[8] Suppose that the world economy consists of two countries, A and B. Assume that $\underline{m_A} < \underline{m_B}$ and $\overline{m_A} < \overline{m_B}$ so that B is the high-income country and A is the low-income one. Incomes for each country are uniformly distributed with a

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[8] The results discussed in Section 3.2 largely carry over to the case of bilateral trade between identical countries. Therefore, competitive pressure induced by trade raises the incentive for product innovation for both countries.

density K. Further assume that there exists a certain level of technology gap such that Country A always produces and sells lower quality than Country B. So we exclude the leapfrogging case from our consideration. For simplicity, assume that only one firm for each country is considering entry into the integrated market. Finally, no transport costs for trade are assumed.

When two countries open to trade, the autarky conditions serve as an initial condition of the trade regime. Under autarky, country B produces higher quality than country A produces. This means that trade creates a foreign competitor producing higher quality to the firm in country A. Similarly, the firm in country B confronts a low quality producer after trade opens. The firms should update their quality-price decisions, since the autarky choice of quality and price would no longer be optimal.

Remark 1 *Given two economies in each of which* $\overline{m_j} > \beta_{k,0}c$ *for* $j = A, B$ *and* $k = H, L$*, suppose that* $\underline{m_B} < \overline{m_A}$*. If* $\underline{m_B} < m^*_{H,L} < \overline{m_A}$ *at the trade equilibrium, then the intra-industry trade arises, i.e., both countries export their quality goods with each other. Otherwise, there exists only unilateral trade from one country to another.*

The pattern of trade depends on the income level of marginal consumers who are indifferent between consuming two products of different qualities. Given that some parts of the income distributions of the two countries overlap, bilateral trade arises only if $\underline{m_B} < m^*_{H,L} < \overline{m_A}$. If $m^*_{H,L} > \overline{m_A}$, then only the low quality producer in Country A would export to Country B. On the other hand, if $m^*_{L,o} < m^*_{H,L} < \underline{m_B}$, the high quality good produced in Country B dominates the integrated market and there exists only unilateral trade with Country B exporting to the other.

The critical income level that shapes the market demand for each product is determined by several factors. Recall that $m^*_{H,L} = \frac{p_H - p_L}{u(q_H) - u(q_L)} = \beta_{H,L}(p_H - p_L)$. In addition, note that equilibrium prices are determined by the income levels of the two countries and consumers′ valuation of each quality. Therefore, given a certain level of product quality, if $\overline{m}$ is relatively higher, the firm producing the higher quality could charge a relatively higher price, because consumers′ willingness to pay for quality rises. This leads to an increase in this critical income level.[9] On the other hand, if the utility gap between consuming two goods of different qualities is larger, then the critical income level decreases and the market demand for the high quality good expands$\left(\text{i.e. } \frac{\partial m^*_{H,L}}{\partial \beta_{H,L}} < 0\right)$.

Finally, consider the following lemma:

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[9] Specifically, $\frac{\partial m^*_{H,L}}{\partial \overline{m_A}} = \frac{\partial m^*_{H,L}}{\partial \overline{m_B}} = \frac{\beta_{H,L} + \beta_{L,0}}{2(3\beta_{H,L} + 2\beta_{L,0})} > 0$ and $\frac{\partial m^*_{H,L}}{\partial \underline{m_B}} = \frac{\beta_{H,L}}{2(3\beta_{H,L} + 2\beta_{L,0})} > 0$

Lemma 2 *Given two closed economies in each of which* $\overline{m_j} > \beta_{k,0}c$ *and* $\overline{m_j} < 2\underline{m_j}$ *for* $j = A, B$ *and* $k = H, L$ *suppose that* $\underline{m_A} < \underline{m_B}$ *and* $\overline{m_A} < \overline{m_B}$ *and* $\underline{m_B} < \overline{m_A}$*. Then, under free trade,* $m^*_{H,L} < \overline{m_A}$ *at the price equilibrium.*

Proof. *See Appendix A*

Lemma 2 implies that there is no case in which low quality goods from country A dominate the integrated market if incomes across consumers are relatively similar. In this circumstance, the equilibrium price of the high quality good is low enough that the firm in Country B gains a substantial market share in the integrated market. If the distribution of incomes for Country B is sufficiently wider, on the other hand, it would be plausible that the profit concern forces the firm producing high quality to charge a price level that , $m^*_{H,L} > \overline{m_A}$. In this case, only the low quality producer in Country A exports to Country B.

3.3.2. Trade and Innovation Incentive

This section examines the relationship between bilateral trade and firms′ incentive to innovate. After considering the case in which the quality gap before innovation is $\Delta k = 1$, we generalize our results to any level of quality gap between two countries. For the sake of simplicity, let $u(q_{k+1}) - u(q_k) = u(q_k) - u(q_{k-1})$ for any k . Then, $\beta_{k,k-1} = \cdots = \beta_{k-n,k-n-1} = \beta$ and $\beta_{k,k-\lambda} = \beta/\lambda$ where $\beta > 0$ is a constant.[10]

Suppose that Country A is currently producing a differentiated good of the lowest quality available (q_L) where $\beta_{L,o} = \beta$, while Country B is producing a good of quality q_H. Consider that the firm in country B invests in product innovation $(q_H \rightarrow q_{HH})$, given that the firm in country A continues to produce q_L. Then the profit maximization problem for each country is as follows:

$$max\, \pi^q_B = (p_{HH} - c)\left(x^A_{HH} + x^B_{HH}\right) - F$$

$$max\, \pi^q_A = (p_L - c)\left(x^A_L + x^B_L\right) - F$$

where $x^j_H = \left[\overline{m_j} - \beta_{HH,L}(p_{HH} - p_L)\right]K$ for $j = A, B$, $x^A_L = \left[\beta_{HH,L}(p_{HH} - p_L) - \beta_{L,0}p_L\right]K$, and $x^B_L = \left[\beta_{HH,L}(p_{HH} - p_L) - \underline{m_B}\right]K$. Similarly, we can

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[10] Let $u(q_{k+1}) + u(q_k) = \bar{u}$ for any k. Then, We have $\beta_{k,k-\lambda} = \frac{1}{u(q_k)-u(q_{k-\gamma})} = \frac{1}{u(q_k)-u(q_{k-1})+u(q_{k-1})-\cdots+u(q_{k-\gamma+1})-u(q_{k-\gamma})} = \frac{1}{\bar{u}+\cdots+\bar{u}} = \frac{1}{\lambda\bar{u}} = \frac{\beta}{\lambda}$

derive the profit of the firm in Country B for the case in which it invests in process innovation:

$$max\,\pi_B^c = (p_H - c + \Delta c_H)\left(x_H^A + x_H^B\right) - F$$

$$max\,\pi_A^c = (p_L - c)\left(x_L^A + x_L^B\right) - F$$

where $x_L^j = [\overline{m_j} - \beta_{H,L}(p_H - p_L)]K$ for $j = A, B$, $x_L^A = [\beta_{H,L}(p_H - p_L) - \beta_{L,0}p_L]K$, and $x_L^B = \left[\beta_{H,L}(p_H - p_L) - \underline{m_B}\right]K$. Our derivation results from these profit maximization problems are presented in Appendix B.[11]

Our results indicate the followings: first, similar to the closed economy case, As the income domestic level becomes higher, other things being equal, then a firm's incentive for product innovation also rises $\left(\frac{\partial \Delta c_H^*}{\partial \overline{m_B}} + \frac{\partial \Delta c_H^*}{\partial \underline{m_B}} = \frac{15\sqrt{2}-14}{28\beta} > 0\right)$. A similar effect is observed for the foreign country's income level$\left(\frac{\partial \Delta c_H^*}{\partial \overline{m_A}} = \frac{20\sqrt{2}-21}{28} > 0\right)$.

At the same time, however, the extent of the increase in the relative incentive for product innovation induced by higher incomes would be smaller under free trade than in the closed economy.[12] Trade induces Country B to exploit the foreign market, in which consumers have a lower willingness to pay for quality than those in Country B. Consequently, the firm in Country B would invest relatively less in quality improvement under free trade than the autarky case.

On the other hand, given that Country B continues to produce q_H, Country A, which is currently producing q_L, has no incentive to invest in product innovation. This is because price competition between products of the same quality leads to zero profit for producers in both countries. Therefore, Country A is unambiguously undertaking process innovation if $\Delta k = 1$, unless it anticipates that Country B pursues product innovation.

Proposition 3 *Under free trade, if the consumers' income of either the home or foreign country is higher, the relative incentive for product innovation over process innovation increases. However, the extent of the increase in the relative incentive for product innovation induced by higher incomes would be smaller under free trade than in the closed economy.*

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[11] We also report the results for the case of $\Delta k = 2$ in the Appendix.

[12] Δc_H^* for Country B under autarky can be calculated using Equation (9):

$$\left.\frac{\partial \Delta c_H^*}{\partial \overline{m_B}}\right|_{autarky} = \frac{\sqrt{\beta_{H,0}} - \sqrt{\beta_{HH,0}}}{\sqrt{\beta_{HH,0}}\beta_{H,0}} = \frac{\sqrt{\beta/2} - \sqrt{\beta/3}}{\sqrt{\beta/3}\,\beta/2} - \frac{\sqrt{6}-2}{\beta}$$

Now we generalize our results for the case of any level of technology gap. Suppose that the current quality gap between the two trading partners is $\Delta k = \lambda$ where $1 \leq \lambda \leq n - 1$. Given the quality level of products produced in the other country, each country makes a decision on the type of innovation it pursues. The equilibrium outcomes are again presented in Appendix B.

In Figures 3.3, we depict the effects of income changes on innovation incentive for Country B, varying the quality gap λ from 1 to 50. Without loss of generality, we assume that $\beta = 1$. As shown in the figure, all values are positive, implying that, regardless of the degree of technology gap between countries, the incentive for product innovation of Country B becomes higher, as the consumers′ income, either domestic or foreign, increases$\left(\frac{\partial \Delta c^*}{\partial \overline{m_A}}\bigg|_B > 0 \textit{ and } \frac{\partial \Delta c^*}{\partial \overline{m_B}}\bigg|_B + \frac{\partial \Delta c^*}{\partial \underline{m_B}}\bigg|_B > 0\right)$.

On the other hand, a higher domestic income, other things being equal, induces a smaller increase in the incentive for product innovation under free trade, relative to the closed economy case.[13] As we discussed in the case of $\Delta k = 1$, international trade with high-income countries implies a creation of additional consumers who have relatively low willingness to pay for quality goods. Therefore, it affects the firm′s incentive for innovation in favor of process innovation.

In Figure 3.3, we can also observe how the incentive change for innovation induced by income growth is changed when the quality gap between countries widens. The effect of domestic income changes on the incentive for product innovation for the firm in Country B tends to increase first if the quality gap is small, but it decreases, as the product quality gap between two countries is getting wider.[14] Recall that the market demand for a product is determined mainly by the income level of marginal consumers who are indifferent between consuming two products of different qualities, $m^*_{k,k-\lambda}$. Given that $m^*_{k,k-\lambda} = \beta_{k,k-\lambda}(p_k - p_{k-\lambda})$, an increase of the market demand through product innovation comes mostly from the changes in $\beta_{k,k-\lambda}$. Note that $\beta_{k,k-\lambda} = \beta/\lambda$ and thus $\beta_{k,k-\lambda} - \beta_{k,k-\lambda+1} = \frac{\beta}{\lambda(\lambda+1)}$. This directly implies that market expansion through providing a product of improved quality is quite limited if the quality gap is large. Therefore, a large initial quality gap strengthens the relative incentive for process innovation for the firm in Country B.

Now consider Country A, As shown in Figure 3.4, relatively a higher income level of the domestic economy encourages the firm in Country A to invest in quality improvement of its own product. Note, however, that the

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[13] Under the autarky, $\frac{\partial \Delta c^*}{\partial \overline{m_B}}\bigg|_{\text{autarky}} = \frac{\sqrt{\lambda}(\sqrt{\lambda+1}-\sqrt{\lambda})}{\beta}$ for any λ. We have that $\frac{\partial \Delta c^*}{\partial \overline{m_B}}\bigg|_{\text{autarky}} > \frac{\partial \Delta c^*}{\partial \overline{m_B}}\bigg|_{\text{trade}} > \frac{\partial \Delta c^*}{\partial \overline{m_B}}\bigg|_B + \frac{\partial \Delta c^*}{\partial \underline{m_B}}\bigg|_B$ for any λ.

[14] Specially, we have that $\left(\frac{\partial \Delta c^*}{\partial \overline{m_B}}\bigg|_B + \frac{\partial \Delta c^*}{\partial \underline{m_B}}\bigg|_B\right)/\partial\lambda < 0$ if $\Delta k \geq 3$.

incentive for product innovation of Country A in fact decreases as the consumers′ income of Country B becomes higher: relatively less reduction in unit costs is needed for the low quality firm in order to match the same level of profits from product innovation. This is quite an interesting result, and our interpretation is as follows: if the consumers′ income is higher, their willingness to pay for quality also rises. Given that quality is produced through outlays on fixed costs rather than marginal costs, the firm in Country B is able to charge a price at a similar level as the low quality product and gain a substantial market share. As long as the firm in Country B provides a product of better quality, therefore, it is relatively hard for the firm in Country A to increase its profit by upgrading the quality of its own product. Consequently, this raises the relative incentive for cost-reducing innovation. The firm in Country A would be better off by providing a low quality at a lower price. Finally, the firm in Country A has less incentive to upgrade the quality of its own product when the quality gap is bigger. The reasoning is similar to the case of Country B. The additional market demand induced by product innovation is limited if the quality gap is large.

IV. The Empirics

4.1. Data Sources and Empirical Strategy

Our analysis draws upon the annual survey of R&D activities and the firm-level export data from the Korean Custom Office. We combine these two data sources by matching them through establishment identity codes. The annual survey of R&D activities contains detailed information on R&D expenditure, research personnel, and R&D activities at the individual firm-level or institution-level. The original data comprises the survey results from public research institutes, universities and colleges, medical institutes and business enterprises, and we keep only business enterprises for estimation. Since our theoretical model is relevant for an analysis for vertically-differentiated products, we use the firm-level data only from the manufacturing sectors that fit this product property; such as computers, telecommunication apparatus, transport equipment including automobiles, etc (See Appendix C). Our sample coverage is around 2,000 firms for each year and the sample period is from 2005 to 2007.

Our data contain the information on individual firms′ R&D expenditure by the following types of usage; new product innovation, existing product improvement, new process innovation and existing process improvement for each firm in the sample. We also use firm-specific information from the data to construct controls variables such as firm′s age, size and sales. Finally, the export data from the Korean Custom Office comprise a complete list of Korean exporters and their top 5 export destination countries.[15] We use the per capita GDP level as one of our key independent variables.[16]

Our estimation equation is as follows;

$$lnRD_{it}^{j} = \alpha_0 + \alpha_1 lnGDPPC_{it} + \alpha_2 lnTECH_{it} + \beta X_{it} + \varphi_i + \theta_t + \varepsilon_{it} \quad (4.1)$$

where $lnRD_{it}^{j}$ is the logged value of R&D investment of type j for firm i at year t, $lnGDPPC_{it}$ the logged value of per capital GDP for the major export destination country of firm i at year t, $lnTECH_{it}$ is the technology level of major trading partner, and X_{it} the vector of control variables including firm′s age, employment size, sales values, and R&D expenditure.17 And φ_i is the unobserved time-invariant individual effect for firm i, θ_t is the vector of year dummies, and ε_{it} is the error term.

In estimation, we are particularly interested in the relationship between income level of trade partner country and the investment propensity to product innovation. We include the squared term of $lnGDPPC_{it}$ in estimation so that non-linear relationship would be possibly allowed.

4.2. Empirical Results

Before discussing our main estimation results, we first examine the difference between exporting firms and non-exporting counterparts. As shown in Table 1, we find strong evidence of exporter′s premium in our sample data, which is consistent with the recent literature of international trade. In our sample data, exporters tend to be larger in size and they are investing more in R&D. The t-test statistics in the last column indicate that the differences in the sizes of asset, capital, sales, employment, and total R&D expenditure between exporters and non-exporters clearly significant.

In addition, Table 1 shows that the size of exporters′ R&D investments are generally largely regardless of different usage. On the other hand, the composition of R&D investments across different types by usage is not much different between exporters and non-exporters. The only noticeable observation is that exporters′ expenditure share on old product improvement tends to be

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[15] Unfortunately, however, we could not get access to export values at the firm-level due to statistical confidentiality regulation.

[16] The values of per capita GDP are obtained from the World Bank′s World Development Indicator database.

[17] Here the technology level of the major export destination country is proxied by its TFP level at current PPPs (USA=1), the data come from Penn World Table 9.0.

slightly higher.

Table 2 presents our estimation results based on Equation (4.1). For the columns (1) and (2), the dependent variable is the logged value of R&D spending on production innovation. As shown in the table, the estimated coefficients of control variables for firm-specific characteristics, such as employment size, sales and age, are statistically significant. Larger firms, both in employment size and sales, spend more on product innovation, while younger firms invest relatively more on it. According to the fixed effect estimation reported in the column (1), a 10% increase in the per capita income of the major trading partner country induces a 0.39% additional R&D spending on product innovation by 0.39%. On the other hand, the TFP level of the partner country seems to be negatively correlated to the R&D expenditure on product innovation; if the TFP level is lower by 1%, then product innovation spending would decrease by 0.15%. On the other hand, in the case of the random effect model, the marginal effect of the technology level of the export destination country is turned out to be statistically insignificant. The Hausman test statistic, reported at the bottom of the table, indicates that the fixed effect estimation seems to be a more sensible model in this case.

We further decompose the R&D spending on product innovation into investment for developing new product and the other for improving the existing product, and run the regressions separately. The results are reported in the columns (1) and (2) in Table 3. While the negative impacts of the TFP of the partner country on product innovation expenditure are still maintained for both regressions, the marginal impact of the income level holds only for the spending on old product improvement. This implies that trade with a higher income country tends to increase firms′ effort to improve their existing products, but different income levels of trading partners do not change the firm′s incentive to develop new products into introduce into the markets.

On the other hand, the estimation results contained in Tables 3 and 4 indicates that, unlike the product innovation case, there exist little evidence on the causal linkage relation between the income or technology level of trading partner and the incentive for process innovation .

Finally, instead of R&D spending levels, we construct another dependent variable by calculating the expenditure share on new product innovation in the total R&D spending (i.e. propensity of production innovation) and re-run the regression. Apparently, this measure seems to be more consistent with our theoretical model in Section III. Our regression equation for this case is as follows;

$$Product_{it}^{share} = \gamma_0 + \gamma_1 lnGDPPC_{it} + \alpha\gamma_2 lnGDPPC_{it}^2 + \delta X_{it} + \mu_i + \pi_t + \omega_{it} \tag{4.2}$$

where $Product_{it}^{share}$ represents the propensity to (new) product innovation. We add the squared term of $lnGDPPC_{it}$ in order to test the possibility of a non-linear relationship with the dependent variable. On the other hand, unlike Equation (4.1), $lnTECH_{it}$ is not included in estimation since its estimated coefficient is not statistically significant.

As presented in Table 4, the estimation results indicate an inverted U-shaped relationship between trading partner′s income level and the R&D expenditure share on ″new″ product innovation. The coefficient for the squared term of $lnGDPPC_{it}$ is statistically significant at the 10% significance level, while that for $lnGDPPC_{it}$ is not. Using the delta method, we re-calculate the overall impact of $lnGDPPC_{it}$ and report the results in Table 5. Consistent with the prediction form our theoretical model in Section III, the net effect of the income level of trading partner on new product innovation is negative with the 5% statistical significance. Therefore, we can conclude that export destination country′s income is relatively higher, then a firm′s relative incentive to invest in new product innovation declines. In addition, our estimation results indicate that the relative incentive to invest in new product innovation tends to increase until the income level of the major trading partner reaches at 5,260 US dollars, then it decreases afterward

V. Concluding Remarks

This paper presents a simple illustrative model that accounts for firms′ decision whether to direct their R&D expenditure towards product innovation or towards process innovation under international trade setting. We examine the factors that would be important in determining relative incentives between product innovation and process innovation in this paper. We show that the consumers′ income and the degree of technological sophistication affect the relative incentives between the two types of innovation.

Frist of all, we find strong evidence of exporter′s premium in our sample data, which is consistent with the recent literature of international trade. In our sample data, exporters tend to be larger in size and they are investing more in R&D. The size of exporters′ R&D investments are generally largely regardless of different types of usage.

Second, our empirical analysis suggests that trade with a country with a higher technology level induces less incentive for product innovation, due to heightened competitive pressure. And finally, consistent with our theoretical model prediction, this paper confirms that the income level of trading partner is negatively correlated with the propensity to invest in new product innovation.

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Table 1. Test for Exporters' Premium

	Non-exporters		Exporters		Difference (t-test statistic)
	Mean	Standard Deviation	Mean	Standard Deviation	
Age	13.52	9.124	15.40	10.316	- 7.09***
lnSales	8.939	1.884	9.724	1.757	-16.24***
lnAsset	8.954	1.700	9.675	1.665	-16.05***
lnCapital	7.046	1.546	7.601	1.590	-13.18***
InSize (Employment)	3.840	0.028	4.369	0.021	-14.95***
lnR&D personnel	2.129	0.021	2.405	0.018	- 9.85***
lnR&D (value)	6.212	0.028	6.644	0.023	-11.69***
for New Product	5.659	0.032	6.059	0.025	- 9.68***
for Old Product	4.975	0.035	5.438	0.027	-10.27***
for New Process	4.578	0.052	4.953	0.042	- 5.48***
for Old Process	4.510	0.051	4.785	0.040	- 4.16***
R&D (relative share)					
New Product	0.546	0.007	0.539	0.005	0.86
Old Product	0.277	0.005	0.292	0.004	-2.18**
New Process	0.083	0.003	0.080	0.002	0.76
Old Process	0.094	0.004	0.089	0.003	1.00
No. of Observations	2,199		3,817		

Note: *, ** and *** indicate that the estimated coefficients are significant at the 10%, 5% and 1% level, respectively.

Table 2. Estimation Results I: R&D Level Equations

	Product Innovation		Process Innovation	
	Fixed Effect (1)	Random Effect (2)	Fixed Effect (3)	Random Effect (4)
lnGDPPC	0.039*	0.039*	−0.022	0.037
	(0.023)	(0.021)	(0.062)	(0.042)
lnTECH	−0.146*	−0.0883	0.049	−0.043
	(0.076)	(0.069)	(0.203)	(0.140)
lnSize	0.248***	0.514***	0.334**	0.576***
	(0.061)	(0.031)	(0.141)	(0.052)
lnSales	0.133***	0.242***	0.210**	0.224***
	(0.032)	(0.022)	(0.088)	(0.039)
Age	−0.009*	−0.0214***	0.0163	−0.020***
	(0.005)	(0.002)	(0.012)	(0.003)
Constant	3.922***	1.927***	1.629	0.521
	(0.433)	(0.257)	(1.161)	(0.498)
R-squared				
Within	0.0694	0.0627	0.0663	0.0509
Between	0.5526	0.5553	0.4221	0.4888
Overall	0.5403	0.5427	0.4309	0.4898
Hausman test				
Chi2 stat.	87.00***		25.34***	
Observations	3,539		1,782	

Note: Year dummies are not reported but included in the regressions. *, ** and *** indicate that the estimated coefficients are significant at the 10%, 5% and 1% level, respectively.

Table 3. Estimation Results II: R&D Level Equations

	New Product Innovation	Old Product Improvement	New Process Innovation	Old Process Improvement
	Fixed Effect (1)	Fixed Effect (2)	Fixed Effect (3)	Random Effect (4)
lnGDPPC	0.033 (0.032)	0.080** (0.036)	0.003 (0.071)	0.044 (0.046)
lnTECH	-0.202* (0.103)	-0.208* (0.117)	0.026 (0.229)	-0.050 (0.155)
lnSize	0.244*** (0.0820)	0.148 (0.0970)	0.285* (0.162)	0.504*** (0.056)
lnSales	0.102** (0.043)	0.134*** (0.050)	0.200** (0.097)	0.281*** (0.042)
Age	-0.011* (0.006)	-0.003 (0.007)	-0.004 (0.012)	-0.019*** (0.004)
Constant	3.918*** (0.584)	2.743*** (0.690)	1.549 (1.290)	-0.405 (0.547)
R-squared Within Between Overall	 0.0491 0.4972 0.4736	 0.0298 0.4925 0.4754	 0.0676 0.4485 0.4697	 0.0491 0.4820. 0.4861
Hausman test Chi2 stat.	 73.31***	 41.51***	 30.30***	 10.50
Observations	3,294	2,998	1,409	1,572

Note: Year dummies are not reported but included in the regressions. *, ** and *** indicate that the estimated coefficients are significant at the 10%, 5% and 1% level, respectively.

Table 4. Estimation Results III: Product R&D Propensity Equations

	Product Innovation (New)		Product Innovation (New + Old)	
	Fixed Effect (1)	Random Effect (2)	Fixed Effect (3)	Random Effect (4)
lnGDPPC	0.159 (0.099)	0.077 (0.073)	-0.038 (0.085)	0.003 (0.062)
$(\ln GDPPC)^2$	-0.009* (0.006)	-0.004 (0.004)	0.002 (0.005)	-0.000 (0.003)
lnSize	-0.014 (0.031)	-0.021** (0.010)	-0.009 (0.026)	-0.004 (0.008)
lnSales	0.008 (0.016)	0.002 (0.007)	0.001 (0.014)	0.002 (0.006)
lnR&D	0.003 (0.014)	0.017*** (0.005)	-0.003 (0.012)	-0.005 (0.005)
Age	0.005** (0.002)	0.001** (0.001)	0.001 (0.002)	0.001** (0.001)
Constant	-0.062 (0.489)	0.181 (0.321)	0.461 (0.419)	0.317 (0.272)
R-squared				
Within	0.0232	0.0185	0.0391	0.0356
Between	0.0056	0.0140	0.0077	0.0189
Overall	0.0096	0.0167	0.0160	0.0257
Hausman test Chi2 stat	173.26***		13.82*	
Observations	3,817		3,817	

Note: Year dummies are not reported but included in the regressions. *, ** and *** indicate that the estimated coefficients are significant at the 10%, 5% and 1% level, respectively.

Table 5. Combined Impact of Trade Partner's Income on Product Innovation

Estimated Coefficient	Standard Error	z	P>|z|	95% Confidence Interval	
-0.0151	0.0067	-2.24	0.025	-0.0283	-0.0019

Note: *, ** and *** indicate that the estimated coefficients are significant at the 10%, 5% and 1% level, respectively.

Figure 1. Incentives for Product and Process Innovation

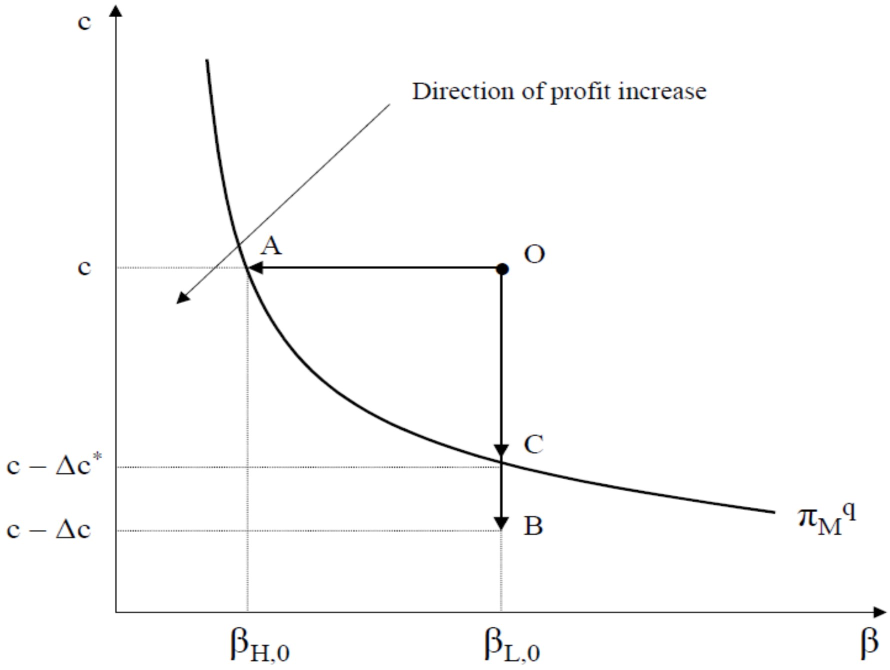


Figure 2. Income Level and Relative Innovation Incentive

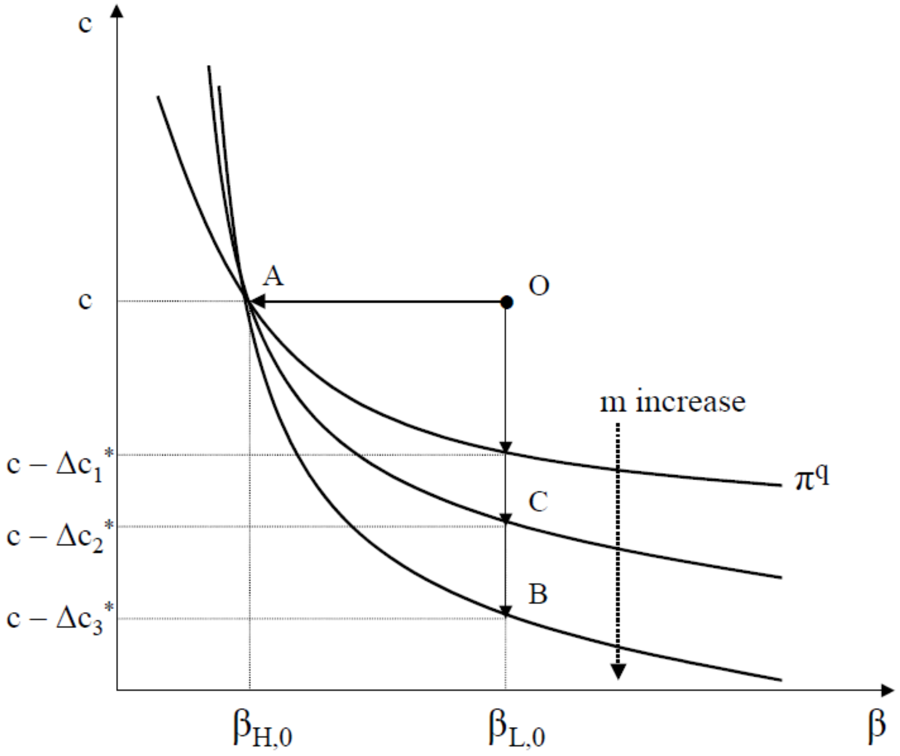
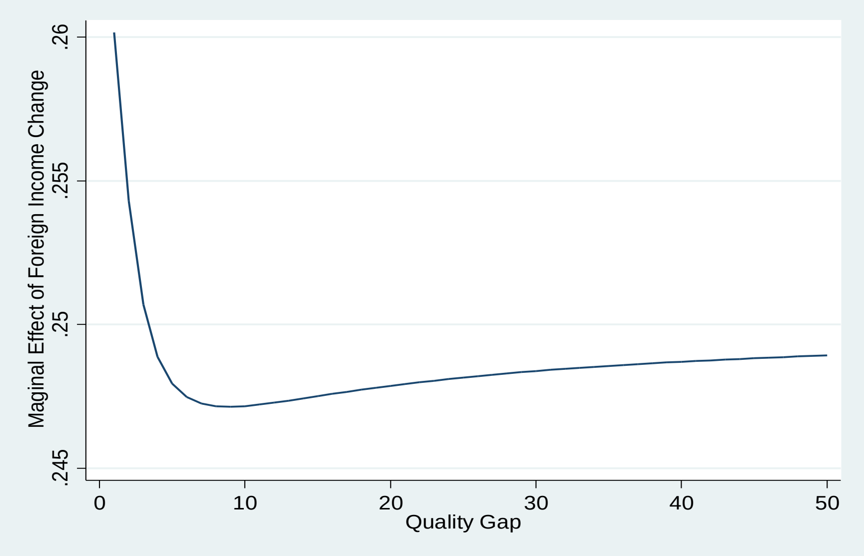
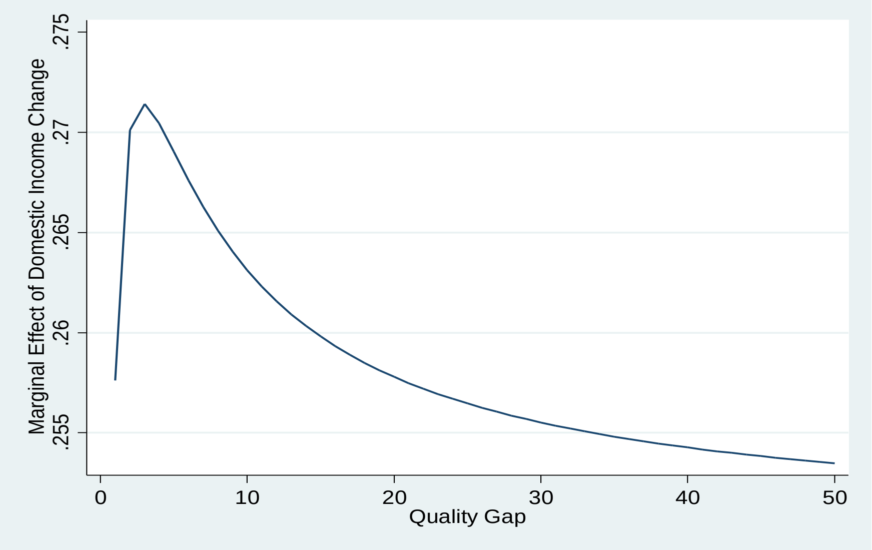


Figure 3. Income Change, Quality gap and Innovation incentive (Coun. B)

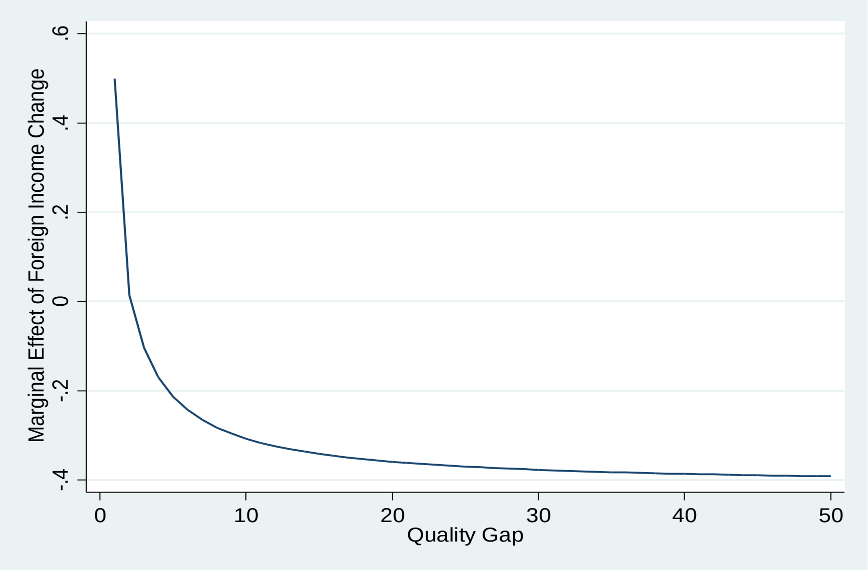


Note: The y-axis represents the marginal effect of the income level on the critical level of cost reduction that makes where a firm is indifferent between product innovation and process innovation

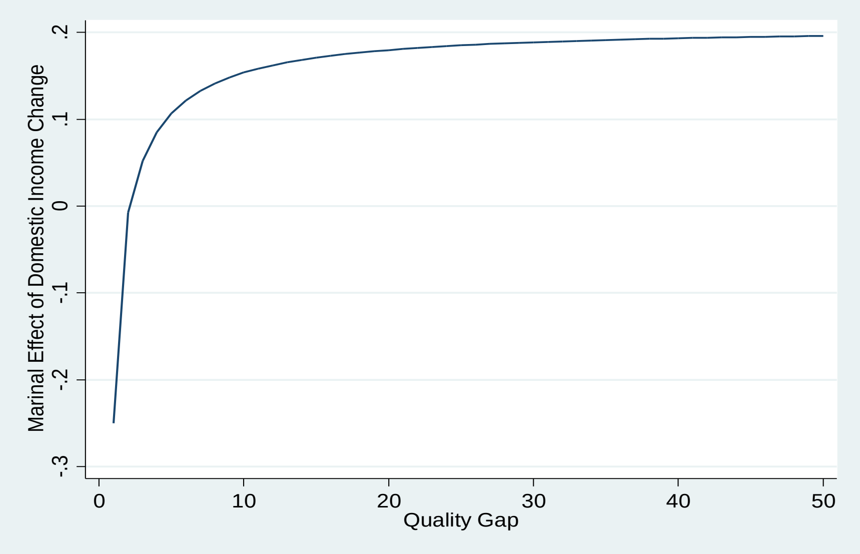


Note: Same as above

Figure 4. Income Change, Quality gap and Innovation incentive (Coun. A)



Note: The y-axis represents the marginal effect of the income level on the critical level of cost reduction that makes where a firm is indifferent between product innovation and process innovation



Note: Same as above

APPENDIX A

1. The Proof of Proposition 2.

Note first that $\beta_{H,0} = \frac{1}{u(q_H)-u_0} = \frac{1}{u(q_H)-u(q_L)+u(q_L)-u_0} = \frac{\beta_{H,L}\beta_{L,0}}{\beta_{H,L}+\beta_{L,0}}$. Using this, we have

$$\left.\frac{\partial \Delta c_L^*}{\partial \bar{m}}\right|_{mono} = \frac{\left(\sqrt{\beta_{L,0}} - \sqrt{\beta_{H,0}}\right)}{\sqrt{\beta_{H,0}}\beta_{L,0}} = \frac{\sqrt{\beta_{L,0}\left(\beta_{H,L}+\beta_{L,0}\right)} - \sqrt{\beta_{H,L}\beta_{L,0}}}{\sqrt{\beta_{H,L}\beta_{L,0}}\beta_{L,0}} = \frac{\sqrt{\beta_{H,L}+\beta_{L,0}} - \sqrt{\beta_{H,L}}}{\sqrt{\beta_{H,L}}\beta_{L,0}}$$

By taking difference between this and that of the duopoly case, we get

$$\left.\frac{\partial \Delta c_L^*}{\partial \bar{m}}\right|_{duo} - \left.\frac{\partial \Delta c_L^*}{\partial \bar{m}}\right|_{mono} = \frac{\left(2\beta_{L,0} + 2\beta_{H,L} - \sqrt{\beta_{H,L}}\sqrt{\beta_{H,L}+\beta_{L,0}}\right)}{\left(\beta_{H,L}+2\beta_{L,0}\right)\sqrt{\beta_{H,L}}\sqrt{\beta_{H,L}+\beta_{L,0}}} - \frac{\sqrt{\beta_{H,L}+\beta_{L,0}} - \sqrt{\beta_{H,L}}}{\sqrt{\beta_{H,L}}\beta_{L,0}}$$

$$= \frac{\left(\beta_{H,L}+\beta_{L,0}\right)\left(\sqrt{\beta_{H,L}+\beta_{L,0}} - \sqrt{\beta_{H,L}}\right)}{\left(\beta_{H,L}+2\beta_{L,0}\right)\beta_{L,0}\sqrt{\beta_{H,L}+\beta_{L,0}}} > 0$$

2. The Proof of Lemma 2.

Suppose instead that $\overline{\mathrm{m_A}} < \mathrm{m}^*_{\mathrm{H,L}}$. A necessary condition for profit maximization implied by Lemma 2 guarantees that $\overline{\mathrm{m_B}} < 2\mathrm{m}^*_{\mathrm{H,L}}$.for high quality firm. But since $\overline{\mathrm{m_A}} < \underline{\mathrm{m_A}}$, $\overline{\mathrm{m_B}} < 2\underline{\mathrm{m_B}}$ and $\underline{\mathrm{m_B}} < \overline{\mathrm{m_A}}$ by assumption and this means that $\overline{\mathrm{m_B}} < 2\overline{\mathrm{m_A}}$, we have $\overline{\mathrm{m_A}} > \frac{\overline{\mathrm{m_B}}}{2} > \mathrm{m}^*_{\mathrm{H,L}}$, which is contradiction. Hence $\overline{\mathrm{m_A}} > \mathrm{m}^*_{\mathrm{H,L}}$.

APPENDIX B

1. Duopoly case (Section 3.2.2)

$$\pi_j^{q^*} = \frac{\left[2\left(\beta_{L,0}+\beta_{H,L}\right)\bar{m} - \beta_{H,L}\beta_{L,0}c - \left(\beta_{L,0}+\beta_{H,L}\right)\beta_{H,L}\Delta c_{-j,L}\right]^2 K}{\beta_{H,L}\left(3\beta_{H,L}+4\beta_{L,0}\right)^2} - F$$

$$\pi_j^{c^*} = \frac{\left(\beta_{L,0}+\beta_{H,L}\right)\left[\bar{m} - 2\beta_{L,0}c + \left(2\beta_{L,0}+\beta_{H,L}\right)\Delta c_{-j,L}\right]^2 K}{\beta_{H,L}\left(3\beta_{H,L}+4\beta_{L,0}\right)^2} - F$$

$$\Delta \mathrm{c}^*_{\mathrm{j,L}} = \frac{\left(2\beta_{L,0} + 2\beta_{H,L} - \sqrt{\beta_{H,L}}\sqrt{\beta_{H,L}+\beta_{L,0}}\right)\bar{m}}{\left(\beta_{H,L}+2\beta_{L,0}\right)\sqrt{\beta_{H,L}}\sqrt{\beta_{H,L}+\beta_{L,0}}}$$

$$-\frac{\left(\beta_{H,L}-2\sqrt{\beta_{H,L}}\sqrt{\beta_{H,L}+\beta_{L,0}}\right)\beta_{L,0}c+\left(\beta_{L,0}+\beta_{H,L}\right)\beta_{H,L}\Delta c_{-j,L}}{\left(\beta_{H,L}+2\beta_{L,0}\right)\sqrt{\beta_{H,L}}\sqrt{\beta_{H,L}+\beta_{L,0}}}$$

2. Equilibrium outcomes under free trade

Case 1. $\Delta k = 1$

For Country B ($\Delta k = 2$ if product innovation is undertaken)

$$\pi_B^{q^*}=\frac{\left[4\overline{m_A}+4\overline{m_A}-\underline{m_B}-\beta c\right]^2}{49\beta}-F$$

$$\pi_B^{c^*}=\frac{\left[3\overline{m_A}+3\overline{m_B}-\underline{m_B}-\beta c+4\beta\Delta c_H\right]^2}{50\beta}-F$$

$$\Delta c^*=\frac{\left(20\sqrt{2}-21\right)(\overline{m_A}+\overline{m_B})+\left(7-5\sqrt{2}\right)\left(\underline{m_B}+\beta c\right)}{28\beta}$$

Case 2. $\Delta k = 2$

For Country B ($\Delta k = 3$ if product innovation is undertaken)

$$\pi_B^{q^*}=\frac{\left[5\overline{m_A}+5\overline{m_A}-\underline{m_B}-\beta c\right]^2}{54\beta}-F$$

$$\pi_B^{c^*}=\frac{\left[4\overline{m_A}+4\overline{m_B}-\underline{m_B}-\beta c+3\beta\Delta c_{Hh}\right]^2}{49\beta}-F$$

$$\Delta c^*=\frac{\left(35\sqrt{6}-72\right)(\overline{m_A}+\overline{m_B})+\left(18-7\sqrt{6}\right)\left(\underline{m_B}+\beta c\right)}{54\beta}$$

$$\frac{\partial\Delta c^*}{\partial\overline{m_A}}=\frac{\partial\Delta c^*}{\partial\overline{m_B}}=\frac{35\sqrt{6}-72}{54\beta},\qquad\frac{\partial\Delta c^*}{\partial\underline{m_B}}=\frac{18-7\sqrt{6}}{54\beta}$$

For Country A ($\Delta k = 1$ if product innovation is undertaken)

$$\pi_A^{q^*}=\frac{5\left[\overline{m_A}+\overline{m_B}-2\underline{m_B}-\beta c\right]^2}{128\beta}-F$$

$$\pi_A^{c^*}=\frac{2\left[\overline{m_A}+\overline{m_B}-2\underline{m_B}-2\beta c+3\beta\Delta c_L\right]^2}{49\beta}-F$$

$$\Delta c^{*}=\frac{\left(7\sqrt{5}-16\right)\left(\overline{m_A}+\overline{m_B}-2\underline{m}\right)+\left(32-7\sqrt{5}\right)\beta c}{49\beta}$$

$$\frac{\partial\Delta c^{*}}{\partial\overline{m_A}}=\frac{\partial\Delta c^{*}}{\partial\overline{m_B}}=\frac{7\sqrt{5}-16}{48\beta},\qquad\frac{\partial\Delta c^{*}}{\partial\underline{m_B}}=\frac{-\left(7\sqrt{5}-16\right)}{24\beta}$$

<u>*Case* 3. Δk = λ</u>

For Country B (for j=A, B)

$$\pi_B^{q^*}=\frac{(\lambda+1)\left[(\lambda+3)(\overline{m_A}+\overline{m_B})-\underline{m_B}-\beta c\right]^2}{2\beta(5+2\lambda)^2}-F$$

$$\pi_B^{c^*}=\frac{\left[\lambda(\lambda+2)(\overline{m_A}+\overline{m_B})-\lambda\left(\underline{m_B}+\beta c\right)+2\beta(\lambda+1)\Delta c\right]^2}{2\beta\lambda(3+2\lambda)^2}-F$$

$$\frac{\partial\Delta c^{*}}{\partial\overline{m_j}}=\frac{\sqrt{\lambda(\lambda+1)}(\lambda+3)(2\lambda+3)-\lambda(\lambda+2)(5+2\lambda)}{2(\lambda+1)(5+2\lambda)\beta}$$

$$\frac{\partial\Delta c^{*}}{\partial\underline{m_B}}=\frac{-\sqrt{\lambda(\lambda+1)}(3+2\lambda)+\lambda(5+2\lambda)}{2(\lambda+1)(5+2\lambda)\beta}$$

$$\frac{\partial\Delta c^{*}}{\partial\overline{m_j}\partial n}=\frac{-2\sqrt{\lambda(\lambda+1)}(50+90\lambda+73\lambda^2+28\lambda^3+4\lambda^4)}{4\sqrt{\lambda}(\lambda+1)^{5/2}(5+2\lambda)^2\beta}+\frac{45+162\lambda+239\lambda^2+174\lambda^3+60\lambda^4+8\lambda^5}{4\sqrt{\lambda}(\lambda+1)^{5/2}(5+2\lambda)^2\beta}$$

$$\frac{\partial\Delta c^{*}}{\partial\underline{m_B}\partial n}=\frac{\sqrt{\lambda(\lambda+1)}(50+40\lambda+8\lambda^2)-3(5+13+12\lambda^2+4\lambda^3)}{4\sqrt{\lambda}(\lambda+1)^{5/2}(5+2\lambda)^2\beta}$$

For Country A (for j=A, B)

$$\pi_A^{q^*}=\frac{(\lambda+3)(\lambda-1)\left[\overline{m_A}+\overline{m_B}-2\underline{m_B}-\beta c\right]^2}{8\beta(2+\lambda)^2}-F$$

$$\pi_A^{c^*}=\frac{(\lambda+2)\left[\lambda(\overline{m_A}+\overline{m_B})-2\lambda\underline{m_B}-2\beta c+2\beta(\lambda+1)\Delta c_L\right]^2}{4\beta\lambda(3+2\lambda)^2}-F$$

$$\frac{\partial\Delta c^{*}}{\partial\overline{m_j}}=\frac{-2\lambda(\lambda+2)^{3/2}+\sqrt{2}\sqrt{\lambda(\lambda-1)(\lambda+3)}(3+2\lambda)}{4(\lambda+1)(\lambda+2)^{3/2}\beta}$$

$$\frac{\partial\Delta c^{*}}{\partial\underline{m_B}}=\frac{4\lambda(2+\lambda)^{3/2}-2\sqrt{2}\sqrt{\lambda(\lambda-1)(\lambda+3)}(3+2\lambda)}{4(\lambda+1)(2+\lambda)^{3/2}\beta}$$

$$\frac{\partial \Delta c^*}{\partial \overline{m_j} \partial n} = \frac{-2\sqrt{\lambda(\lambda+3)(\lambda-1)}(\lambda+2)^{5/2} + \sqrt{2}(\lambda(\lambda+2)(6+14\lambda+3\lambda^2)-9)}{4\sqrt{\lambda(\lambda+3)(\lambda-1)}(\lambda+1)^2(\lambda+2)^{5/2}\beta}$$

$$\frac{\partial \Delta c^*}{\partial \underline{m_B} \partial n} = \frac{2\sqrt{\lambda(\lambda+3)(\lambda-1)}(\lambda+2)^{5/2} - \sqrt{2}(\lambda(\lambda+2)(6+14\lambda+3\lambda^2)-9)}{2\sqrt{\lambda(\lambda+3)(\lambda-1)}(\lambda+1)^2(\lambda+2)^{5/2}\beta}$$

APPENDIX C: Industry Coverage

ISIC Code (Rev3)	Industry
29	Manufacture of machinery and equipment n.e.c.
30	Manufacture of office, accounting and computing machinery
31	Manufacture of electrical machinery and apparatus n.e.c.
32	Manufacture of radio, television and communication equipment and apparatus
33	Manufacture of medical, precision and optical instruments, watches and clocks
34	Manufacture of motor vehicles, trailers and semi-trailers
35	Manufacture of other transport equipment