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Selling High-Tech Inputs to the Enemy

Abstract

Trade wars are being waged by the United States and Japan. Exports of high-tech inputs (e.g., fluorinated polyimides in semiconductor devices) are now curbed by these countries. Manufacturing high-quality outputs require the use of high-tech inputs. Exports of high-tech inputs may not only increase the Northern innovator's profit in the short run but also may create permanent rivals in the downstream market in developing countries. This paper investigates whether it is profitable for a Northern innovator to export high-tech inputs to foreign competitors who would compete in the downstream market. If wage disparity exists between the two countries when products are differentiated, selling the high-tech input to foreign competitors may be mutually beneficial for both the innovator and the foreign rivals in the South. When the finished products are homogeneous, selling only the high-tech input to a sufficiently large number of Southern firms, and exiting from the finished product market, may increase the innovator's profit.

Highlights:

• It may be mutually profitable for the Northern innovator and Southern rivals to export and import the high-tech input in the homogeneous model.

• When the final products are perfect substitutes, there is no incentive for the Northern innovator to sell the high-tech input to two Southern rivals.

• It may be profitable for the Northern firm to stop producing the finished product, and to sell only the high-tech input to a sufficiently large number of Southern rivals.

JEL Codes: F100, L100.

Keywords: high-tech input, export control, high-quality product.

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1. Introduction

President Trump unwittingly may have started a global trade war. The National Defense Authorization Act for Fiscal Year 2019 bans the U.S. government from using Huawei and ZTE products, treating China as a strategic rival or enemy. In July 2019, Japanese Prime Minister Shinzo Abe also announced export curbs on chips and smartphone materials to South Korea, effectively treating it as an enemy: fluorinated polyimides, photoresists, and hydrogen fluoride. According to the Japanese government report, in 2019, Japan produces about 90% of fluorinated polyimides, about 70% of etching gas, and around 90% of photoresists worldwide. These market shares suggest that Japan is practically a monopolist of these high-tech inputs. South Korea's imports of these materials from Japan accounted for 94% of its fluorinated polyimides, 44% of its etching gas, and 92% of its photoresist consumed. (Reuters, 2019) An excessive export control reduces not only the profit of the input-importing foreign firms but also that of the domestic input suppliers.

Sony, one of the early developers of the organic light-emitting diode (OLED) technology, as well as Philips, a European electronics firm, now imports display panels from L.G. Electronics. L.G. is acting both as an input supplier and a downstream seller, manufacturing the OLED panels for these T.V.s (Techrada.com). JOLED Inc., a joint venture of Japan Display, Sony, and Panasonic, was set up to break the monopoly of Samsung and L.G. (Pioneer Reports, 2019) L.G. does not limit its export of display panels to its rival retailer, Sony. Neither does Samsung curb its exports of OLED display screens for smartphones to Apple.

Ordover et al. (1990) demonstrate that the foreclosure of downstream firms does not necessarily increase the profit of a vertically integrated firm. Baumol and Sidak (1994) consider the regulation of natural monopolies and propose an efficient component-pricing rule that the price of an input should exceed marginal production cost.[1] Economides (1998) suggests that an input monopolist may charge a high price for an essential ingredient to raise the entry barrier of potential downstream rivals. Selling inputs to competitors is different from outsourcing. When a firm outsources intermediate goods or a process to a foreign company, there is no competition between the outsourcer and outsourcee.

Arya, Mittendorf, and Sappington (2008) show that when a monopolistic input supplier is also its retail rival, the latter may pay the price above its in-house production cost of the input. Kabiraj and Sinha (2016) consider the case where the rival firm either purchases the low-tech input or buys the patent from the high-tech input supplier to produce a high-quality product. They show that if the quality gap is small, the rival does not purchase the high-tech input. Manova and Yu (2017) suggest that manufacturing goods of higher quality requires high-quality intermediate inputs. Moresi and Schwartz (2017) show that a vertically integrated input monopolist may benefit from selling inputs in the upstream market to a rival using a two-part tariff.

The literature has not examined the optimal pricing of the inputs sold to foreign rivals competing in the downstream market. Specifically, a high-tech monopolist may benefit from selling the high-tech input to a potential foreign rival in the downstream market. We show that the optimal price of the part sold to an international competitor exceeds marginal production cost. For example, Apple purchases display panels from Samsung, even if the price is higher than its marginal production cost.

The purpose of this paper is to consider whether it is profitable for a Northern innovator to export a high-tech input to Southern downstream firms, which are potential enemies in the South. On the one hand, due to wage differences between the countries, exporting the high-tech input raises the profit of the high-tech input producer. On the other hand, exports of such high-tech-inputs to foreign firms create competitors in the finished product market in developing countries. We show that under certain conditions, it pays for the Northern innovator to export the high-tech input to foreign firms even if it creates permanent rivals.

Section 2 describes the benchmark model in which the Northern innovator is a monopolist of the high-quality product in the South. Section 3 introduces inverse demand functions when the Northern and Southern firms produce differentiated products. In Section 4, we consider a differentiated triopoly model in the South and show that under certain conditions, it is profitable for the Northern innovator to export the high-tech input to Southern rivals, who then compete with the innovator in the market for the high-quality product. Section 5 considers a homogenous triopoly model, in which selling the high-tech input to Southern rivals reduces the innovator's profit. Section 6 examines whether the innovator exporting only the high-tech input is profitable, whereas Section 7 contains concluding remarks.

2. Regional Monopoly

Northern Innovator

Hallak (2006) found that capital and skill-abundant countries use their endowment advantages to produce high-quality products and received higher prices. As a benchmark, consider a monopoly market in the South served by an innovative Northern firm. The innovator produces a high-quality product in the North and exports it to the South. The innovator decides on the product quality, and the quality choice is a discrete variable due to technological reasons. For example, mobile phones have evolved from 1G to 5G. The Northern innovator decides whether 3- or 5-nanometer semiconductor chips are to be used in smartphones for mobile communication, and an intermediate quality (e.g., 4.5 nanometers) is not feasible. Once the quality choice is made, plant facilities are built for mass production of the chips. Manova and Yu (2017, p. 119) suggest that the manufacturing of a high-quality product requires not only skilled workers but also high-tech intermediate inputs. For example, smartphones are produced using Samarium cobalt cube magnets for autofocusing in extreme temperatures, even near absolute zero (0^{o} K, or -273^{o} C).

The Northern firm incurs input cost QY when producing Y units of a high-quality product. Antoniades (2015) assumed convex quality-upgrading cost of quality, including innovation costs. In this paper, we assume innovation cost is sunken, and consider only the production cost of the high-tech input. Assume that one unit of high-tech input is used to produce one unit of high-quality products. Production of high-quality T.V. sets provides a good example in that each T.V. set uses one unit of the high-tech screen, the organic light-emitting diode (OLED) display panel. In addition to the production cost of the high-tech input, the innovator incurs assembly cost $\Theta = a_{LY}W$ per unit, where W denotes the Northern wage rate and a_{LY} is the amount of labor required to produce one unit of output Y. Thus, the total production cost of the Northern firm is

$$C(Q,Y) = (\Theta + Q)Y. \tag{1}$$

The Northern innovator chooses Y to maximize its profit in the South

$$\Pi^{M} = PY - C(Q,Y) = \left(A + Q - Y\right)Y - \left(\Theta + Q\right)Y,$$

and the first-order condition is:

$$\frac{\partial \Pi^M}{\partial Y} = A - 2Y - \Theta = 0. \tag{2}$$

The monopoly output and price are:

$$\begin{aligned} Y^M &= \frac{A-\Theta}{2}, \\ P^M &= \frac{A+2Q+\Theta}{2}. \end{aligned} \tag{3}$$

The innovator's profit in the South is

$$\Pi^M = \left(P^M - Q - \Theta\right)Y^M = \left(\frac{A-\Theta}{2}\right)^2. \tag{4}$$

3. Basic Model: Selling High-Tech Input to Two Rivals

While the Northern innovator is the only producer of the high-quality product in the previous scenario, its assembly cost is higher than if the parts were assembled in the South, due to the higher wage in the North. Accordingly, there is room for a Southern firm to enter the market, using the high-tech inputs supplied by the Northern firm. Moreover, the innovator's sale of the high-tech input to Southern firms may be profitable if the input price is higher than the unit cost of the high-tech input.

Recent theoretical works show that the production of high-quality products requires high-tech inputs (i.e., Kugler and Verhoogen, 2012; Hallak and Sivadasan, 2013). Although quality upgrading may raise the Southern firms' profits in developing countries, their inability to produce high-tech input is an entry barrier to the firms in the South. Imports of high-tech input enable the Southern firms to overcome the technology barrier in the high-quality product market.

We consider a second scenario in which the Northern innovator sells the high-tech input to two Southern firms so that they can start producing a high-quality product in the South. The Northern innovator is assumed to sell the high-tech input simultaneously to two Southern firms. Their products are identical since they use the same high-tech input and incur the same assembly costs. Qualcomm is a U.S. innovator producing the wireless 5G chip. [2] Huawei and Xiaomi use Qualcomm's chips to produce 5G smartphones in China, and consumers view them as homogenous substitutes. Consumer demands for the three high-quality products depend on their quality and quantities.[3] Accordingly, the inverse demand functions depend on product quality and quantities, as in Ishi (2014), Taba (2016), and Choi and Choi (2019).

The general utility function of the representative Southern consumer may be written as $U(x_1, x_2, Y, Q)$, where x_1, and x_2 are the quantities of the Southern firms, Y is the output of the Northern innovator, and Q is the common quality level of the products. Since the Southern firms use the same high-tech input, the Northern and Southern products are physically identical. However, consumers may view the Northern and Southern products as imperfect substitutes.

Dixit (1979) and Singh and Vives (1984) used a quadratic utility function to derive linear inverse demand functions. Foster et al. (2008) and Antoniades (2015) used similar quality-adjusted quadratic utility functions. In this paper, we adopt their approach to include product qualities. Specifically, consumer preferences are affected by the common product quality Q, which is determined by the Northern firm. The quality-adjusted quadratic utility function of three goods, x_1, x_2, and Y, is written as:

$$U(x_1, x_2, Y) = \left((A+Q)(x_1 + x_2 + Y) - \frac{x_1^2 + x_2^2 + Y^2 + 2x_1x_2 + 2s(x_1 + x_2)Y}{2} \right) \qquad (5)$$

where A and Q are positive parameters, and s is an index of perceived product differentiation in the eyes of the consumer, indicating the substitutability between x_i and Y for $i = 1, 2.$ Since the Southern firms produce homogenous products, they are perfect substitutes. As the quality of the product (Q) increases, the representative consumer's willingness pay ($A + Q$) also rises. Note that goods x_1, x_2, and Y contain the same high-tech ingredient. Nevertheless, when $0 < s < 1$, the Northern and Southern products may be perceived as differentiated by consumers. For instance, Sony and Panasonic imports display panels from L.G. Electronics, and Japanese consumers view their T.V. sets as differentiated products. When $s = 1$, consumers do not distinguish the two products and view them as perfect substitutes.

Demands for Northern and Southern Products

We first investigate whether it is profitable for the Northern innovator to sell the high-tech input to Southern firms, which would then use it to produce the high-quality product and compete with the Northern firm in the Southern market. Assume that without purchasing the high-tech input, the Southern firms cannot enter the market. That is, the high-tech input is an entry barrier to them. Recall that the quality level Q is a discrete variable, and the Northern innovator determines its choice for technological reasons.

In the beginning, the Northern firm introduces a high-quality product such as a 5G smartphone in the South. Assume that the Southern firms do not sell their products to the

Northern market, and consider input trade between the Northern innovator and two Southern firms. For example, Sony and Panasonic, Japanese producers of electronic devices, provide an example of the high-tech input trade between rivals. Sony and Panasonic purchase OLED display panels from L.G. Electronics, a Korean firm, to make the high-quality T.V. sets, and all three firms compete in the Japanese T.V. market.

Consider now a heterogeneous triopoly model in which the Northern and Southern products are viewed as differentiated goods in the eyes of the Southern representative consumer. The Southern firms purchase the high-tech input from the Northern innovator and sell high-quality products, competing with the Northern innovator in the South. The two varieties (x_i and Y) for i = 1, 2, are imperfect substitutes. From the utility function in (5), we obtain the inverse demand functions for goods Y, x_1, and x_2,

$$\begin{aligned} P_Y &= A + Q - Y - s\left(x_1 + x_2\right), \\ P_1 = P_2 &= A + Q - sY - \left(x_1 + x_2\right), \end{aligned} \tag{6}$$

where P_i is the price of x_i, i = 1, 2, and P_Y is the price of Y. The prices of the Northern and Southern products depend on the quality and quantities of their products. Foster et al. (2008) and Antoniades (2015) employed similar linear inverse demand functions to include the quality of the product and substitutability with other products. In this paper, we adopt a substitutability measure s.

In the first stage, the Northern innovator chooses firms to sell high-tech inputs and sets the price b of the high-tech input within a range that can guarantee positive profits for both the Northern innovator and the Southern competitors. In sections 4 and 5, we assume that the innovator sells the high-tech input to two Southern firms. Let $X \equiv x_1 + x_2$ denote the total output of the high-quality product produced by the two Southern competitors. Once the price of the high-tech input *b* is set, the Southern firms purchase *X* units of the high-tech input and produce an equal quantity of the high-quality product. The Nothern innovator and the Southern firms compete in the market for the finished products.

In this paper, we consider three cases: (i) differentiated triopoly, (ii) homogeneous triopoly, and (iii) homogenous oligopoly with more than three firms. Recall that quality choice was made by the Northern innovator, based on technological reasons such as OLED panels. Even when the three products contain an identical ingredient, consumers may view them as differentiated products. On the other hand, grains produced using Monsanto seeds are ordinarily considered as homogenous, even though different farmers produce them.

4. Differentiated Triopoly

Nothern Innovator

Recall that innovator sells the high-tech inputs to two Southern rivals who employ low-wage workers to differentiate their products from the Northern brand. Once the price of the high-tech input *b* is set in the first stage, the three firms choose quantities in the second stage. The innovating firm optimizes output Y to maximize its profit:

$$\begin{aligned}\Pi_d^C &= P_Y Y + bX - C(Y, X) \\ &= \left(A + Q - Y - s\left(x_1 + x_2\right)\right)Y + b\left(x_1 + x_2\right) - (\Theta + Q)Y - Q\left(x_1 + x_2\right),\end{aligned} \tag{7}$$

where $C(Y, x_1 + x_2) = (\Theta + Q)Y + Q\left(x_1 + x_2\right)$ is the total cost of producing the finished product *Y and* the high-tech input $X = x_1 + x_2$. Q is the unit production cost of the high-tech input and indicates the quality level. Note that the total quantity of the high-tech input produced is $(x_1 + x_2 + Y)$, and of these, only X units are sold to the Southern competitors. The total output of the high-quality product of the Southern rivals is also X.

First, we consider whether selling high-tech input to the Southern firms is profitable. Differentiating (7) with respect to x_i and evaluating it at $x_1 = x_2 = 0$ yields

$$\left.\frac{\partial \Pi_d^C}{\partial x_i}\right|_{x_1 = x_2 = 0} = b - sY^M - Q.$$

Selling one unit of the necessary input to the rivals increases its revenue by $\left(b - sY^M\right)$ where Y^M is the monopoly output, while its production cost rises by Q. Thus, selling the essential input is profitable when the input price b exceeds the minimum price $b_{\min} = sY^M + Q$. This implies that it is profitable for the innovating firm to sell the high-tech input to its Southern rivals initially, provided that the price of the high-tech input is above the lower threshold price $b_{\min}$. Substituting the monopoly output Y^M in (3) into the lower threshold price, we obtain the lower-limit price

$$b_{\min} = \frac{sA + 2Q - s\Theta}{2}. \tag{8}$$

The Nothern innovator also chooses Y to maximize its profit. Differentiating the innovator's profit (7) with respect to Y, we have

$$\frac{\partial \Pi_d^C}{\partial Y} = A - s\left(x_1 + x_2\right) - 2Y - \Theta = 0. \tag{9}$$

Equation (9) shows the Nothern innovator's best response, $Y(x_1, x_2)$, to the output choices of the Southern firms. That is, the Northern firm's output Y decreases as the quantities of its rivals increase.

Southern Rivals

In order to produce a high-quality product, the Southern firms must purchase the high-tech input from the Northern innovator, and hire local workers to complete the production process. Let θ denote the assembly cost per unit of the high-quality product in the South. Due to lower-wage, the unit assembly cost in the South is less than in the North, i.e., $\Theta > \theta.$ Thus, the total cost of the high-tech product has two components: the Southern competitors not only pay *b* for the high-tech input per unit to the Northern innovator but also incur the assembly cost θ per unit. Thus, Southern firm *i*'s total production cost is written as

$$c(x_i) = (b+\theta)x_i. \tag{10}$$

Southern competitor *i* chooses x_i to maximize its profit

$$\begin{aligned} \pi_i^C &= Px_i - (\theta+b)x_i \\ &= \left(A+Q-sY-x_1-x_2\right)x_i - (\theta+b)x_i. \end{aligned} \tag{11}$$

where π_i^C is the profit of Southern firm *i*. Differentiating (11) with respect to x_i for $i = 1, 2$, we have

$$\begin{aligned} \frac{\partial \pi_1^C}{\partial x_1} &= A+Q-sY-x_2-2x_1-\theta-b=0, \\ \frac{\partial \pi_2^C}{\partial x_2} &= A+Q-sY-x_1-2x_2-\theta-b=0. \end{aligned} \tag{12}$$

Equation (12) defines Southern firm *i*'s best response function $x_i(Y, x_j)$, for $i \neq j$, to the Northern innovator's output choice *Y* and the other firm's output x_j.

We now consider whether it is profitable for firm *i* to enter the market, which is served heretofore only by the Northern innovator. Evaluating the left side of (12) at $x_i = 0$, we have

$$\left.\frac{\partial \pi_i^C}{\partial x_i}\right|_{x_i=x_j=0} = A+Q-sY^M-\theta-b.$$

This implies that buying the necessary input from the Northern innovator increases each Southern firm's profit initially, provided that $A+Q-sY^M>\theta+b.$

Once the Southern firms enter the market, their unit production costs are $(\theta+b)$. Purchasing the high-tech input from the Northern innovator is profitable initially, only when marginal revenue ($A+Q-sY^M$) exceeds its unit production cost $(\theta+b)$. Let $b_{\max}=A+Q-sY^M-\theta$ denote the upper threshold price of the high-tech input. When the price of the high-tech input is lower than the upper threshold price $b_{\max}$, it is profitable at first for each Southern competitor to produce a high-quality product. However, as output increases, its profit eventually reaches a maximum and declines after that.

The upper-limit price is

$$b_{\max}=\frac{(2-s)A+2Q+s\Theta-2\theta}{2}. \tag{13}$$

Using the first-order conditions of the innovator in (9) and the Southern competitors in (12), we obtain the Cournot outputs $\left(x_1^C, x_2^C, Y^C\right)$ of the Southern and Northern firms:

$$\begin{aligned} x_1^C = x_2^C &= \frac{(2-s)A+2Q+s\Theta-2\theta-2b}{6-2s^2}, \\ Y^C &= \frac{(3-2s)A-2sQ-3\Theta+2s\theta+2sb}{6-2s^2}. \end{aligned} \tag{14}$$

The total quantity of the high-quality product of the Southern firms is

$$X^C = x_1^C + x_2^C = \frac{(2-s)A+2Q+s\Theta-2\theta-2b}{3-s^2}.$$

Substituting the outputs of the high-quality products in (14) into the prices of goods *Y* and *X* in (6), we have

$$P_Y = \frac{(3-2s)A + \left(6-2s-2s^2\right)Q + \left(3-2s^2\right)\Theta + 2s\theta + 2sb}{6-2s^2},$$
$$P_1 = P_2 = \frac{(2-s)A + 2Q + s\Theta + \left(4-2s^2\right)\theta + \left(4-2s^2\right)b}{6-2s^2}. \tag{15}$$

Optimal Pricing of the High-Quality Input

We have demonstrated that even when that the innovator's assembly cost is higher ($\Theta > \theta$), under certain conditions, it is mutually profitable for the Northern innovator to export, and the two Southern competitors to import the high-tech input. For any given price of the high-tech input, the output choices of the Northern firm and its two Southern rivals constitute a Cournot equilibrium, which is dependent on the input price.

We now consider the optimal pricing of high-tech input. Substituting (8) into the innovator's profit function, we have

$$\begin{aligned}\Pi_d^C &= P_Y Y + b\left(x_1 + x_2\right) - (\Theta + Q)Y - Q\left(x_1 + x_2\right)\\ &= \frac{\left((3-2s)A - 2sQ - 3\Theta + 2s\theta + 2sb\right)^2}{\left(6-2s^2\right)^2}\\ &+ \frac{(b-Q)\left((4-2s)A + 4Q + 2s\Theta - 4\theta - 4b\right)}{6-2s^2}.\end{aligned} \tag{16}$$

Differentiating the innovator's profit in (16) with respect to *b*, we have

$$\frac{\partial \Pi_d^C}{\partial b} = \frac{\left(6-4s^2+s^3\right)A + 2\left(6-3s^2\right)Q - s^3\Theta - \left(6-4s^2\right)\theta - 2\left(6-3s^2\right)b}{4\left(3-s^2\right)^2} = 0.$$

Note that $0 < s < 1$, when the two products are imperfect substitutes. Then

$\frac{\partial^2 \Pi_d^C}{\partial b^2} = -\frac{3\left(2-s^2\right)}{2\left(3-s^2\right)^2} < 0.$ It follows that the optimal price of the high-tech input is unique,

$$b^C = \frac{\left(6-4s^2+s^3\right)A + 2\left(6-3s^2\right)Q - s^3\Theta - \left(6-4s^2\right)\theta}{2\left(6-3s^2\right)}. \tag{17}$$

Substituting the optimal price of the high-tech input into the outputs in (14), Cournot equilibrium outputs are written:

$$\begin{aligned} Y^C &= \frac{\left(6-2s-s^2\right)A - \left(6-s^2\right)\Theta + 2s\theta}{2\left(6-3s^2\right)}, \\ x_1^C = x_2^C &= \frac{\left(1-s\right)A + s\Theta - \theta}{\left(6-3s^2\right)}. \end{aligned} \tag{18}$$

If $\left(1-s\right)A + s\Theta - \theta > 0$, the outputs of the Southern firms are positive, $x_1^C = x_2^C > 0.$

Substituting the optimal price of the high-tech input in (17) into the prices of goods Y, x_1, and x_2 in (15), we have

$$\begin{aligned} P_Y &= \frac{\left(3-2s\right)A + \left(6-2s-2s^2\right)Q + \left(3-2s^2\right)\Theta + 2s\theta + 2sb}{6-2s^2}, \\ P_1 = P_2 &= \frac{\left(2-s\right)A + 2Q + s\Theta + \left(4-2s^2\right)\theta + \left(4-2s^2\right)b}{6-2s^2}. \end{aligned} \tag{19}$$

Recall that the upper- and lower-threshold prices of the high-tech input are

$b_{\max} = \frac{\left(2-s\right)A + 2Q + s\Theta - 2\theta}{2}$ and $b_{\min} = \frac{sA + 2Q - s\Theta}{2}$. Comparing the lower and upper threshold prices of the high-tech input, we obtain

$$b_{\max} - b^C = \frac{2\left(3-s^2\right)\left(\left(1-s\right)A + s\Theta - \theta\right)}{2\left(6-3s^2\right)} > 0,$$
$$b^C - b_{\min} = \frac{\left(3-2s^2\right)\left(\left(1-s\right)A + s\Theta - \theta\right)}{2\left(6-3s^2\right)} > 0. \quad (20)$$

Intuitively, this implies that if the price of the high-tech input lies in the interval $\left(b_{\min}, b_{\max}\right)$, then it is mutually profitable for the Northern and Southern firms to export and import the high-tech input, i.e., $\Pi_d^C > \Pi^M$, and $\pi_1^C = \pi_2^C > 0$.

Recall that *X* and *Y* are imperfect substitutes $(0 < s < 1)$, and the unit assembly cost in the South is lower than in the North $\left(\Theta - \theta > 0\right)$. Since the Southern firms earn some profit from purchasing the high-tech input, there is no reason for the Southern firms to boycott the high-tech input of the Northern innovator. This result is summarized below:

Proposition 1: Assume that the unit assembly cost is lower in the South than in the North, $(\Theta > \theta)$, $\left(1-s\right)A + s\Theta - \theta > 0,$ and the Northern and Southern products are differentiated, i.e., x_i and *Y* are imperfect substitutes $(0 < s < 1)$. In the Cournot equilibrium, the price of the high-tech input lies between the lower and the upper thresholds, $b_{\min} < b < b_{\max}$. Thus, it is mutually profitable for the Northern innovator to export and for the Southern firms to import the high-tech input ($\Pi_d^C > \Pi^M$, and $\pi_1^C = \pi_2^C > 0.$)

5. Homogenous Triopoly

Next, consider the case where the three products, x_1, x_2, and *Y*, are viewed as perfect substitutes in the eyes of consumers. In this situation, *s* = 1 in equation (8), and these goods emerge only one product, and the same price P is charged for the finished products, whether the Northern or Southern firms produce them. The common inverse demand function reduces to: $P = A + Q - Y - x_1 - x_2$. We now investigate whether trading of the high-tech input is profitable for both the Northern innovator and the two Southern firms.

Nothern Innovator

Once the Northern innovator sells the high-tech input to two Southern firms and sets its price in the first stage, the Northern innovator and the Southern firms compete in the second stage. The innovating firm chooses Y to maximize its profit:

$$\begin{aligned}\Pi^C &= PY + bX - C(Y, x_1, x_2) \\ &= \left(A + Q - Y - x_1 - x_2\right)Y + bX - (\Theta + Q)Y - Q\left(x_1 + x_2\right)\end{aligned} \tag{21}$$

where $C(Y, x_1, x_2) = (\Theta + Q)Y + Q\left(x_1 + x_2\right)$ is the total production cost of the finished good Y and the high-tech input $\left(x_1 + x_2\right)$, and Q is the unit production cost of the high-tech input. Once the price of the high-tech input b is announced, the Northern innovator chooses Y, and the Southern firms choose x_1, and x_2.

First, we consider whether it is profitable for the Northern innovator to sell the high-tech input to the Southern rivals. Differentiating (21) with respect to x_i and evaluating it at $x_1 = x_2 = 0$ yields

$$\left.\frac{\partial \Pi^C}{\partial x_i}\right|_{x_1 = x_2 = 0} = b - Y - Q.$$

Prior to the entry of the Southern firms, the Northern firm is a monopolist, producing Y^M. Thus, if the price of the high-tech input is greater than $Y^M + Q$, then it is profitable for the innovator to sell the high-tech input to its Southern rivals at first. The lower threshold price of the high-tech input is

$$b_{\min} = \frac{A + 2Q - \Theta}{2}. \tag{22}$$

Differentiating the innovator's profit (21) with respect to *Y*, we have the innovator's best response function, $Y(x_1, x_2)$, implicitly defined by the first-order condition,

$$\frac{\partial \Pi^C}{\partial Y} = A - x_1 - x_2 - 2Y - \Theta = 0. \tag{23}$$

Southern Rivals

Southern firm *i*'s profit is

$$\begin{aligned} \pi_i^C &= Px_i - (\theta + b)x_i \\ &= \left(A + Q - Y - x_1 - x_2 \right) x_i - (\theta + b)x_i. \end{aligned} \tag{24}$$

where π_i is the profit from the high-quality product. The first-order condition is:

$$\frac{\partial \pi_i^C}{\partial x_i} = A + Q - Y - 2x_i - \theta - b = 0. \tag{25}$$

Evaluating the left side of (25) at $x_1 = x_2 = 0$, we have

$$\left. \frac{\partial \pi_i^C}{\partial x_i} \right|_{x_1 = x_2 = 0} = A + Q - Y^M - \theta - b.$$

If the price of the high-tech input is below the upper threshold price, $b_{\max} = A + Q - Y^M - \theta$, then buying the necessary input from the Northern innovator increases each Southern firm's profits initially.

The upper threshold price of the high-tech input is

$$b_{\max} = \frac{A + 2Q + \Theta - 2\theta}{2}. \tag{26}$$

Using the first-order condition of the innovator in (23) and those of Southern competitors in (25), we obtain Cournot equilibrium outputs, Y, x_1, and x_2:

$$\begin{aligned} Y^C &= -Q - \Theta + \theta + b, \\ x^C = x_1^C = x_2^C &= \frac{A + 2Q + \Theta - 2\theta - 2b}{2}. \end{aligned} \tag{27}$$

Substituting these outputs into the price of high-quality product, we obtain

$$P^C = \theta + b. \tag{28}$$

Optimal Pricing of the High-Quality Input in Homogenous Triopoly

As in a differentiated triopoly, we assume that the Northern innovator is the price setter of the high-tech input, and consider the optimal price setting in a homogeneous triopoly market. In the first stage, the Northern innovator sets the price of the high-tech input, *b*. Substituting (8) into the innovator's profit function, we have

$$\begin{aligned} \Pi^C &= \left(P_Y^C - \Theta - Q\right)Y^C + \left(b - Q\right)\left(x_1^C + x_1^C\right) \\ &= \left(-Q - \Theta + \theta + b\right)^2 + \left(b - Q\right)\left(A + 2Q + \Theta - 2\theta - 2b\right). \end{aligned} \tag{29}$$

Differentiating the Northern innovator's profit in (29) with respect to *b*, we have

$$\frac{\partial \Pi^C}{\partial b} = A + 2Q - \Theta - 2b = 0.$$

Since $\frac{\partial^2 \Pi^C}{\partial b^2} < 0,$ the optimal price of the high-tech input is unique,

$$b^C = \frac{A + 2Q - \Theta}{2} \tag{30}$$

Recall that the upper- and lower-threshold prices are $b_{\max} = \dfrac{A+2Q+\Theta-2\theta}{2}$ and $b_{\min} = \dfrac{A+2Q-\Theta}{2}$. Comparing the threshold prices with the optimal price of the high-tech input, we have

$$\begin{aligned} &b_{\max} - b^C = \Theta - \theta > 0, \\ &b^C - b_{\min} = 0. \end{aligned} \tag{31}$$

Substituting the optimal price of the high-tech input into the optimal quantities in (27), we obtain optimal outputs:

$$\begin{aligned} &Y^C = \frac{A-3\Theta+2\theta}{2}, \\ &x_1^C = x_2^C = \Theta - \theta. \end{aligned} \tag{32}$$

Since $\Theta - \theta > 0,$ the optimal quantities of the Southern firms are positive, $x^C > 0.$ If $A - 3\Theta + 2\theta > 0,$ then the innovator's output is also positive. Using the price of the high-tech input and the optimal quantities in (30) and (32), we obtain the price of the high-quality product,

$$P^C = \frac{A+2Q-\Theta+2\theta}{2},$$

and the profit of the innovator is

$$\Pi^C = \left(\frac{A-3\Theta+2\theta}{2}\right)^2 + \left(\frac{A-\Theta}{2}\right)(\Theta-\theta). \tag{33}$$

Comparing the monopoly profit of the innovator Π^M in (4) and the profit in (33), we find that if the innovator's output is positive, $A - 3\Theta + 2\theta > 0,$ then the innovator's profit in the

Cournot model is less than the monopoly profit, i.e, $\Pi^C - \Pi^M = -\left(\frac{A-3\Theta+2\theta}{2}\right)(\Theta-\theta) < 0.$[4]

This implies that if the high-quality products are perfect substitutes, the innovator earns a positive profit in the Cournot equilibrium, but selling the high-tech input to the two Southern firms reduces its profit.

Next, recall that the price of a high-quality product is $P^C = b^C + \theta$. Southern firm *i*'s profit for $i = 1, 2,$ is

$$\pi_i^C = \left(P^C - b^C - \theta\right)x_i = 0. \tag{34}$$

This result shows that each Southern firm's economic profit is zero. That is, if the high-quality products are homogenous, entry of Southern firms stops after two firms have entered. These results are summarized below:

Proposition 2: Assume that the unit assembly cost is lower in the South than in the North, $\theta < \Theta,$ and the high-quality products sold by the Northern innovator and the two Southern rivals are perfect substitutes. Even if the price of the high-tech input is set so that the profits of the Southern firms are zero ($\pi_1 = \pi_2 = 0$), the Northern innovator's profit cannot rise above the monopoly profit, i.e., $\Pi^C < \Pi^M$. Thus, there is no incentive for the Northern innovator to sell the high-tech input to the Southern rivals.

6. To Be or Not To Be in High-Quality Product Market

In Sections 4 and 5, we assumed that the Northern innovator not only sells the high-tech input to Southern competitors but also exports the finished high-quality product to the Southern market. When the innovator introduces a new or high-quality product, consumers in the South may be willing to pay a premium to purchase the brand product. Accordingly, in the initial stage, differentiated oligopoly may describe the reality in the Southern market. However, as consumers become more familiarized with the Southern products, brand loyalty to the original innovator may gradually decline. Thus, the Northern innovator may have been profitable in a differentiated oligopolistic market at first. As the Southern market progressively evolves into a homogenous oligopoly, the innovator cannot revert to its initial monopolistic status in the Southern market.

If the products of the Northern and Southern firms are considered as indistinguishable in the eyes of consumers in the Southern market, there is no reason for the innovator to incur high costs than the Southern firms and to sell the costlier product at the same price as the Southern firms. We now investigate whether the innovator exits from the finished product market in the South and specializes only in the production of the high-tech input. For instance, Japanese firms have maintained near-monopolies for high-tech inputs such as photoresists, hydrogen fluoride, and fluorinated polyimides in worldwide, and these materials are needed in the production of high-quality products. Korean firms (S.K. Hynix and Samsung) rely on Japanese inputs to produce memory chips.

In this section, we investigate the conditions under which the Northern innovator quits the production of the finished product altogether and specializes only in the production of the high-tech inputs. In the first stage, the Northern innovator fixes the price of the high-tech input and exports it to n Southern firms. In the second stage, n Southern firms produce high-quality products using the imported high-tech input. Recall that consumers view all finished products as perfect substitutes. In this case, $s = 1$ in equation (8). Recall that the Northern innovator is at a disadvantage in that its assembly cost in the North is higher than the Southern competitors. Thus, we consider the case when the Northern innovator sells only high-tech inputs (Y = 0). The inverse demand function for the finished product reduces to:

$$P = A + Q - \sum_{j=1}^{n} x_j. \tag{35}$$

Southern Firms

The Southern firms pay b for the high-tech input per unit to the Northern innovator and incur assembly cost θ per unit. Firm i's total production cost for $i = 1, \cdots, n,$ is written as

$$c(x_i) = (\theta + b)x_i. \tag{36}$$

Firm i chooses x_i to maximize its profit

$$\pi_i = Px_i - (b+\theta)x_i = \left(A + Q - \sum_{j=1}^{n} x_j - b - \theta \right) x_i. \tag{37}$$

Differentiating (37) with respect to x_i, we obtain the first-order condition for good i, $i = 1, \cdots, n,$

$$\frac{\partial \pi_i}{\partial x_i} = A + Q - 2x_i - \sum_{j \neq i} x_j - \theta - b = 0. \tag{38}$$

Since the Southern firms have identical production costs, their output levels are the same,

$$x_i = \frac{A + Q - \theta - b}{n+1}. \tag{39}$$

Optimal Pricing of the High-Tech Input:

Recall that the Nothern innovator observes the quantities of the Southern firms in the second stage. In the first stage, the innovator sets the price, *b*, of the high-tech input. The innovating firm's profit is

$$\Pi = \left(b - \Theta\right)\left(\sum_{j=1}^{n} x_j\right) = \left(b - \Theta\right)\left(\frac{nA + nQ - n\theta - nb}{n+1}\right). \qquad (40)$$

Differentiating the innovator's profit in (40) with respect to *b*, we have

$$\frac{\partial \Pi}{\partial b} = \left(\frac{nA + nQ + n\Theta - n\theta - 2nb}{n+1}\right) = 0, \qquad (41)$$

and $\frac{\partial^2 \Pi}{\partial b^2} = -\frac{2n}{n+1} < 0.$ From the first-order condition in (41), we obtain the optimal price of the high-tech input:

$$b^* = \frac{A + Q + \Theta - \theta}{2}. \qquad (42)$$

Substituting (42) into (39), we obtain the optimal output of Southern firm *i*,

$$x_i^* = \frac{A + Q - \Theta - \theta}{2\left(n+1\right)}. \qquad (43)$$

Since $b^* - Q > 0,$ we note $A - Q + \Theta - \theta > 0.$ Substituting the outputs in (43) into the price of the finished product, we have

$$P^* = \frac{\left(n+2\right)A + \left(n+2\right)Q + n\Theta + n\theta}{2\left(n+1\right)}.$$

Profits of the Northern innovator and the Southern firms are

$$\Pi^* = \left(b^* - Q\right)\sum_{j=1}^{n} x_j^* = \frac{\left(A - Q + \Theta - \theta\right)\left(A + Q - \Theta - \theta\right)n}{4\left(n+1\right)},$$
$$\pi_i^* = \left(P^* - b^*\right)x_i^* = \left(\frac{A + Q - \Theta - \theta}{2\left(n+1\right)}\right)^2 = \left(x_i^*\right)^2. \tag{44}$$

Since $b^* > Q$ and $x_i^* > 0,$ the innovator's profit is positive $\left(\Pi^* > 0\right).$ Differentiating (44) with respect to *n*, we have

$$\frac{\partial \Pi^*}{\partial n} = \frac{\left(A - Q + \Theta - \theta\right)\left(A + Q - \Theta - \theta\right)}{4\left(n+1\right)^2} > 0,$$
$$\frac{\partial^2 \Pi^*}{\partial n^2} = -\frac{2\left(A - Q + \Theta - \theta\right)\left(A + Q - \Theta - \theta\right)}{4\left(n+1\right)^3} < 0. \tag{45}$$

This shows that as the Northern innovator sells the high-tech input to more firms, the innovator's profit increases, but at a decreasing rate.

Case 1: One Southern Firm

Now consider that the Northern innovator sells the high-tech input to only one Southern firm. The profits of the Northern innovator and Southern firm in (44) are reduced to

$$\Pi^*\Big|_{n=1} \frac{\left(A - Q + \Theta - \theta\right)\left(A + Q - \Theta - \theta\right)}{8},$$
$$\pi_i^*\Big|_{n=1} = \left(\frac{A + Q - \Theta - \theta}{4}\right)^2. \tag{46}$$

Comparing the innovator's profit from selling the high-tech input to one Southern firm to the monopoly profit, we find that the monopoly profit is higher than the innovator's profit selling high-tech input to one Southern firm, i.e., $\Pi^M - \Pi^*\big|_{n=1} > 0.$[5] However, selling the high-tech input to more Southern firms increases the innovator's profit.

Case 2: *n* approaches infinity

Evaluating the innovator's profit (44) as n approaches infinity, we have

$$\Pi^*\big|_{n\to\infty} = \frac{\left(A-\theta+\Theta-Q\right)\left(A-\theta+Q-\Theta\right)}{4} = \frac{(A-\theta)^2-(\Theta-Q)^2}{4}. \tag{47}$$

Comparing the innovator's profit to the monopoly profit, we obtain

$$\Pi^*\big|_{n\to\infty} - \Pi^M = \frac{\left(A-Q+\Theta-\theta\right)\left(A+Q-\Theta-\theta\right)}{4} - \left(\frac{A-\Theta}{2}\right)^2. \tag{48}$$

If the unit cost Q of the high-tech input lies between the unit-assembly costs in the South and the North, i.e., $\theta < Q < 2\Theta - \theta$, then as n approaches infinity, the profit of the Northern innovator from selling the high-tech input to the Southern firms approaches Π^*, which is higher than the innovator's monopoly profit obtained when selling no high-tech inputs to Southern firms, $\Pi^*\big|_{n\to\infty} - \Pi^M > 0.$[6]

Recall that when n = 1, $\Pi^M - \Pi^*\big|_{n=1} > 0.$ That is, monopoly profit is higher than when the innovator specializes in the high-tech input and sell it to a single Southern firm. However, selling the input to more firms increases the innovator profit. When n approaches infinity, eventually selling the high-tech input to infinitely many Southern firms raises the profit above the monopoly level, i.e., $\Pi^*\big|_{n\to\infty} - \Pi^M > 0.$ Thus, there exists an m for which $\Pi^*\big|_{n} - \Pi^M > 0,$ for all $n > m$.

Proposition 3: Assume that all finished products are homogenous, and the unit cost Q of the high-tech input lies between the assembly costs in South and North, $\theta < Q < 2\Theta - \theta$. When the Northern innovator sells the high-tech input to a single Southern firm, the innovator's profit is less than the monopoly profit. However, as the innovator sells its input to more firms, the innovator's profit increases, and there exists an m such that the innovator's profit from selling the high-tech input to n firms, $1 < m \le n$, exceeds the monopoly profit and Southern firms earn positive profits, i.e., $\Pi^*|_m > \Pi^M$ and $\pi_m^* > 0$.

7. Concluding Remarks

In recent years export control has been used in the United States and elsewhere. The National Defense Authorization Act of 2019 categorically prohibits U.S. firms from supplying products to Huawei and ZTE. Similarly, the Japanese Prime Minister, Shinzo Abe, imposed new rules in 2019, restricting Japan's exports of hydrogen fluoride, photoresists, and fluorinated polyimides (etching gas) in order to hamper the production of DRAM and NAND flash memories produced by Korean firms. While export control measures may be politically motivated, such policies would undoubtedly have economic consequences.

This paper has demonstrated that when the products are differentiated, it pays for the U.S. innovator to export high-quality input to foreign rivals in the downstream markets of developing countries. Conversely, prohibiting exports of the high-tech input and creating an entry barrier to the potential enemy may be detrimental to the national economy. Creating a technological entry barrier to foreign rivals not only decreases the innovator's profit in the short run but may also encourage the rival's spending to build the production capacity of the high-tech input. Hence, the technological barrier can thereby create a permanent competitor in the upstream market in the long run. By exporting the high-tech input and discouraging R&D expenditure of the rival Southern firms, the high-tech input producer may encourage the long-run dependency of the foreign rival firms on the high-tech inputs.

This paper considered whether it is profitable for a Northern innovator to export the high-tech input, which creates a foreign rival in the downstream market. In the case of a differentiated triopoly model in the South, under certain conditions, exporting the high-tech input to Southern rivals is shown to be profitable. When the finished products are homogeneous, due to high wages in the North, it may increase the innovator's profit to specialize only in the production of the high-tech input and to exit from the finished product market.

Japanese Prime Minister Shinzo Abe, in August 2019, announced to remove South Korea from its white list, effectively establishing barriers to export essential inputs in the semiconductor industry. These export curbs only encouraged the in-house production of these inputs by South Korean firms, thereby permanently reducing their dependency on the Japanese inputs. While international politics and national safety play a role in determining trade policies such as export controls in the U.S. and Japan, export controls in key input industries may produce the butterfly effect on trading countries.

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[1] “optimal input price is the input’s direct per-unit incremental cost plus the opportunity cost for the input supplier of the sale of a unit of input.” (Baumol and Sidak, 1994, p. 178)

[2] For example, the Federal Trade Commission claimed that Qualcomm has acted as a monopolist (The Verge, 2019).

[3] In contrast, Choi and Choi (2018) suggested that when an innovator in a developed economy exports a high-quality product to a developing country, a copycat firm may enter, charging a lower price.

[4]

$$\Pi^C - \Pi^M = \left(\frac{A-3\Theta+2\theta}{2}\right)^2 + \left(\frac{A-\Theta}{2}\right)(\Theta-\theta) - \left(\frac{A-\Theta}{2}\right)^2$$

$$= \left(\frac{A-\Theta}{2}\right)^2 + \left(\frac{3\Theta-2\theta-A}{2}\right)(\Theta-\theta) - \left(\frac{A-\Theta}{2}\right)^2 .$$

$$= -\left(\frac{A-3\Theta+2\theta}{2}\right)(\Theta-\theta) < 0.$$

[5]

$$\Pi^M - \Pi^*\big|_{n=1} = \frac{(A-\Theta)^2}{4} - \frac{(A-Q+\Theta-\theta)(A+Q-\Theta-\theta)}{8}$$
$$> \frac{(A-\theta)^2}{4} - \frac{(A-Q+\Theta-\theta)(A+Q-\Theta-\theta)}{8}$$
$$= \frac{(A-\theta)^2}{8} + \frac{(Q-\Theta)^2}{8} > 0.$$

[6] $\theta < Q < 2\Theta - \theta$ is a sufficient condition for

$$\Pi^*\big|_{n\to\infty} - \Pi^M = \frac{(A-Q+\Theta-\theta)(A-\Theta+Q-\theta)}{4} - \left(\frac{A-\Theta}{2}\right)^2 > 0.$$