THE UNIVERSITY OF TEXAS AT SAN ANTONIO, COLLEGE OF BUSINESS

Working Paper SERIES

WP # 0001ECO-414-2011

Date August 5, 2011

Outsourcing: Volume and Composition of R&D

Hamid Beladi
University of Texas at San Antonio
USA

Sugata Marjit
Centre for Studies in Social Sciences
India

Lei Yang
The Hong Kong Polytechnic University
Hong Kong

Copyright © 2011, by the author(s). Please do not quote, cite, or reproduce without permission from the author(s).

UTSA COLLEGE OF BUSINESS KNOWLEDGE FOR A NEW WORLD

ONE UTSA CIRCLE
SAN ANTONIO, TEXAS 78249-0631
210 458-4317 | BUSINESS.UTSA.EDU

Outsourcing: Volume and Composition of R&D

Hamid Beladi[a], Sugata Marjit[b,d], Lei Yang[c,*]

[a]*University of Texas at San Antonio, USA,*
[b]*Centre for Studies in Social Sciences, India*
[c]*The Hong Kong Polytechnic University, Hong Kong*
[d] *GEP, Nottingham*

June 2011

Abstract

This paper examines the impact of the outsourcing of production on the volume and composition of the home country's research and development. We find that outsourcing decreases the process R&D of the multinational firm in large markets when it only conducts process R&D (*the substitution effect between outsourcing and process R&D*). Outsourcing tends to emerge as a complementary factor to product development when the multinational firm conducts both product R&D and process R&D (*the complementary effect between outsourcing and product R&D*) under some conditions. This implies that international outsourcing has a different effect on product innovation and process innovation.

JEL Classification: D23; F12; L22; O31; O33
Keywords: Outsourcing, Product R&D, Process R&D

[*]**Corresponding author**: Lei Yang, Faculty of Business, The Hong Kong Polytechnic University, Kowloon, Hong Kong; (852) 3400 3457; aflyang@inet.polyu.edu.hk.
We thank Nancy Chau and the two referees for their helpful comments and suggestions.

1. Introduction

International outsourcing has emerged as a hotly debated issue in developed countries where different groups, policy commentators, and politicians have criticized the process for its impact on local employment. The impacts of international outsourcing of production on wage rates, productivity, organizational forms, and welfare have been well documented.[1] Grossman and Helpman (2002) and Antràs and Helpman (2004) show how the choice among international outsourcing, vertical integration, and FDI are affected by cost of governance, search frictions, and contract incompleteness, within sectoral heterogeneity and variations in industry characteristics. Bandyopadhyay and Wall (2010) analyze the relationship between immigration and outsourcing in a general-equilibrium model of international factor mobility. Jones (2005) finds with outsourcing the relative and real wage rate of the country's labor force are raised if the country also produces a more capital-intensive commodity for world markets.

The increased extent of international outsourcing not only changes the pattern of production but also triggers changes in the pattern of non-production activities, such as research and development.

Prior literature has analyzed the linkage between outsourcing and process R&D. Marjit and Mukherjee (2008) show that process R&D will not be promoted through outsourcing if the innovating firm enjoys large market shares. Che, Yang, and Zhang (2010) study how the outsourcing of intermediate goods affects process R&D

[1] See Grossman and Helpman (2002, 2003), Antràs and Helpman (2004), Jones (2005), Chen et al. (2004), Mukherjee (2007), and Mukherjee and Dinda (forthcoming), among others.

investment. They find that by outsourcing the intermediate-good production to intermediate-good specialized producers, firms can lower production costs and spend more on R&D activities but face the risk of information leakage. With a certain degree of patent protection, firms invest in R&D activities when outsourcing their intermediate goods. Chen and Sen (2010) investigate the impact of upstream outsourcing on downstream process R&D investment. On the one hand, a decrease in a competitor's costs helps to increase the demand of upstream goods. Hence it can lower the upstream price through economy of scale, which can enhance process R&D investment. On the other hand, it mitigates downstream competition, which can reduce process R&D investment.

The aforementioned studies all focus on the impact of outsourcing on process R&D. However, empirical evidence suggests that product R&D investment plays an important role in firms' R&D activities. Scherer and Ross (1990) show that product R&D accounts for around three-fourths of total R&D investments by US firms. Imai (1992) shows that product R&D is around two-fifths of the total R&D budget for Japanese firms. Some empirical literature (Mansfield, 1981; Cohen and Klepper, 1996) demonstrates the impact of market concentration and firm size on the choice between product R&D and process R&D. Theoretical studies also have analyzed relationships between product R&D and process R&D. In particular, Lin and Saggi (2002) investigate the relationship between process and product R&D and find firms invest more in product R&D when they can do process R&D than when they cannot, because process R&D also increases equilibrium output levels by lowering costs of

production and therefore makes product R&D more attractive. Rosenkranz (2003) analyzes simultaneous product and process R&D and finds that firms invest more in R&D under coordination than that under competition and shift the optimal proportion of R&D investment towards product innovation.

Prior literature has paid little attention to the combination of international outsourcing and the interaction between product R&D and process R&D to establish the linkage among outsourcing, product R&D, and process R&D. Our paper fills this void by offering a new perspective on the impact of outsourcing and illustrates the effects of the international outsourcing of production on the volume and composition of the home country's research and development by the joint consideration of two types of R&D.

We explicitly study how the surge of international outsourcing alters the composition of firms' R&D in the home country when they undertake both product and process innovations. We construct a model in which two firms in a developing country, one multinational (the N firm) and one local (the S firm), produce a differentiated product. The multinational firm is able to do process innovation to reduce labor content in its production process as well as do product R&D to increase the degree of product differentiation. The N firm can serve the developing country either through exporting or outsourcing. We first consider a scenario in which the N firm serves the developing country through exporting. Next we analyze the impact of outsourcing on the N firm's R&D activities when that firm's entry mode is changed from exporting to outsourcing.

In a three-stage game where the N firm chooses product R&D investments in the first stage and process R&D investments in the second stage and then two firms engage in Cournot competition in the third stage, we find the following results. First, outsourcing reduces process R&D in large markets if the multinational firm only conducts process R&D. Second, outsourcing promotes product R&D but tends to discourage process R&D if the multinational firm conducts both product R&D and process R&D under some conditions. Therefore, outsourcing tends to emerge as a complementary factor to product development but as a substitute for process R&D.

Our paper is most closely related to that of Marjit and Mukherjee (2008). They show that R&D will not be promoted through outsourcing if the innovating firm enjoys large market shares. They approach the problem from the perspective of industrial organization literature and highlight the detrimental role of outsourcing on cost-reducing R&D in a model with homogenous goods. In contrast, we focus on the role of international outsourcing when firms are able to do both product development and process innovation in an oligopoly model in differentiated goods. We show that international outsourcing has a different effect on product innovation and process innovation when we consider the interaction of product innovation and process innovation.

Our paper has clear empirical relevance. There is considerable empirical evidence that demonstrates the relationship between outsourcing and total R&D activities in the home country. Feenstra and Hanson (1999) find that the outsourcing of intermediate goods leads to the increase in the demand for non-production workers

in the US. Hijzen, Gorg, and Hine (2005) show that international outsourcing is one of the important components in explanations of the changing skill structure of manufacturing industries in the UK, and it has a positive impact on R&D activity. Becker and Ekholm (2008) illustrate that there is only a weak relationship between German MNEs' offshore employment and the occupational workforce composition, but there is a statistically significant positive relationship between offshore employment and the proportion of non-routine and interactive tasks. Our paper might be a good design for future empirical study on the effect of outsourcing on the change in the composition of firms' R&D. More specifically, our theoretical model leads to two empirical predictions. First, for firms that only conduct process R&D, outsourcing reduces process R&D in large markets. Second, for firms that conduct both product R&D and process R&D, outsourcing promotes product R&D but discourages process R&D.

In terms of the testable implications of the model, our paper is also related to the literature on the knowledge acquisition of MNCs in host countries. In particular, Almeida (1996) and Frost (2001) find that foreign subsidiaries can be used as a means of accessing knowledge from host countries. Singh (2007) finds that there are not only significant knowledge inflows from MNCs to the host country but also significant knowledge outflows back from the host country to MNCs. The above literature shows that knowledge from a local partner is a channel for MNCs to accumulate knowledge and develop R&D. In a departure from the previous literature, by establishing a link between outsourcing and resource reallocation from production to innovation, our

model exhibits a different channel of promoting the R&D investment of MNCs.

The rest of paper is organized as follows. In section 2 we present a simple model with only process R&D and analyze the impact of outsourcing on process R&D. In section 3 we construct a model with both product and process R&D and demonstrate the effects of outsourcing in production on the composition of R&D. In section 4 we use parametric functions to provide numerical analysis. We study the welfare implications of R&D investment in the presence of international outsourcing in section 5. We conclude in section 6.

2. The basic setup

We develop a model that allows us to study the effects of outsourcing on the volume and composition of R&D. Consider a world in which a multinational firm (the N firm) and a local firm (the S firm) produce differentiated goods and compete in the developing country. The representative consumer's utility function is given by[2]

$$u(q_1, q_2, m) = a(q_1 + q_2) - \frac{q_1^{\ 2} + q_2^{\ 2}}{2} - sq_1q_2 + m, \quad 0 \le s \le 1.$$

Here, m is the numeraire good; q_1 and q_2 are the consumption of goods produced by the N firm and the S firm respectively; s represents the degree of substitutability between the two products. Products are homogeneous as $s = 1$ and are unrelated

[2] Following Rosenkranz (2003), the main difference between this model and vertical differentiation models (Shaked and Sutton, 1982, 1983) is that in this model there is no heterogeneity in tastes and the consumer consumes a bit of every available good instead of consuming his most preferred product. We also tried the vertical differentiation model in Appendix D and find that our findings remain qualitatively intact with the vertical differentiation model.

as $s = 0$.[3] Utility maximization gives rise to the following marginal utility functions:

$$MU_1 = a - q_1 - sq_2$$

$$MU_2 = a - q_2 - sq_1.$$

Note that the quantity of good 2 will have less negative effect on the marginal utility of good 1, as the products are more differentiated from the above expressions of marginal utility functions.

We assume that labor is the only factor of production. Let α and β denote the labor requirement for producing one unit of output of the N firm and the S firm respectively. We assume that the N firm has superior technology; hence, we have $\alpha < \beta$. Let w and w_L represent the wage rates of the developed country (the Northern country) and the developing country (the Southern country) respectively. We thus have $w > w_L$. Accordingly, the S firm's marginal production cost is $w_L \beta$. The N firm, however, can serve the Southern market either through exporting or outsourcing. The N firm's marginal production cost is $w\alpha$ under exporting, as it keeps production in the Northern country. It becomes $w_L \alpha$ under outsourcing. Outsourcing in this paper means allocating the entire product line to a developing country to take advantage of lower wages in the developing country, leaving only the R&D function in the home country. In principle, both exporting and outsourcing incur fixed costs. An exporting firm must find and inform foreign buyers about its product and learn about the foreign market, research the foreign regulatory environment, adapt its product to ensure that it conforms to foreign standards, set up new distribution

[3] Based on Shy (1996), we have the assumption that $0 \le s \le 1$. This implies that the effect of increasing q_1 on p_1 is larger than the effect of the same increase in q_2. That is, the price of a brand is more sensitive to a change in the quantity of this brand than to a change in the quantity of the competing brand.

channels in the foreign country, and conform to all the shipping rules specified by the foreign customs agency (Roberts and Tybout, 1977; Melitz, 2003). An outsourcing firm incurs fixed costs related to technology transfer costs and transaction costs (Grossman and Hart, 1986). As the fixed costs under exporting and those under outsourcing do not affect equilibrium R&D investment, we assume that there are no fixed costs related to exporting or outsourcing in our model. This assumption is made to minimize technical details that are not essential for our results. Our findings remain intact if we relax this assumption.

We assume that the N firm can do process innovation to reduce labor content in its production process. Hence, the marginal cost of production for the N firm is $w\alpha(r)$ under exporting with process innovation. Here, r is the amount of process R&D investment. We posit that the N firm's unit labor requirement is negatively related to its process R&D investment. Therefore $\alpha'(r) < 0$. For simplicity, we also assume $\alpha(r)$ is concave in r, or $\alpha''(r) < 0$. R&D investment incurs both fixed costs and variable costs. Examples of fixed costs include laboratory costs and equipment costs; examples of variable costs include salary to researchers and material consumed. Suppose F and $Z(r)$ denote the fixed costs and variable costs of process R&D respectively. We further assume that the fixed costs of process R&D are large enough so that only the multinational firm finds it profitable to undertake R&D.[4]

[4] This assumption is based on the observation that inward technology transfer instead of innovation remains the primary source of new information for effective technical change in most developing counties (Fink and Maskus, 2004). There are several reasons for this. First, R&D in certain industries, for example, the pharmaceutical industry, is highly complex and prohibitively expensive. Evidence shows that, in the pharmaceutical industry, most R&D activity by Indian-owned firms has concentrated on imitating and adapting products developed in foreign countries, and very little R&D has been geared toward the development of new drugs (Fink and Maskus, 2004). Second, financial constraints in developing countries affect domestic firms' innovations (Gorodnichenko and Schnitzer, 2009). Third, firms in developing countries have low innovative capacity. Chin and Grossman (1990), Deardorff (1992), and Helpman (1993) assume that the South does not have innovative capacity.

$Z(r)$ increases with the N firm's process R&D investment. Therefore we have $Z' > 0$. We also assume that $Z'' > 0$ to satisfy the second-order condition. Let π_1 and π_2 denote the profit of the N firm and the S firm respectively.

We initially focus on the scenario in which the N firm only undertakes process R&D. The time sequence of the game is as follows. At stage 1 the N firm chooses process R&D; at stage 2 both firms compete in quantities in a Cournot setting and profits are realized. We solve the game through backward induction.

We begin by analyzing the case when the N firm serves the Southern country through exporting. The maximization problem for the N firm in the production stage is

$$\underset{q_1}{Max}(a - q_1 - sq_2)q_1 - w\alpha(r)q_1 \qquad (1)$$

And the maximization problem for the S firm in the production stage is

$$\underset{q_2}{Max}(a - q_2 - sq_1)q_2 - w_L\beta q_2 \qquad (2)$$

The optimal quantities of the N firm and the S firm satisfy

$$q_1 * = \frac{2[a - w\alpha(r)] - s(a - w_L\beta)}{4 - s^2} \qquad (3)$$

$$q_2 * = \frac{2[a - w_L\beta] - s[a - w\alpha(r)]}{4 - s^2} \qquad (4)$$

Therefore, the N firm's maximization problem in the process R&D stage is[5]

$$\underset{r}{Max}\left\{\frac{2[a - w\alpha(r)] - s(a - w_L\beta)}{4 - s^2}\right\}^2 - F - Z(r) \qquad (5)$$

Let $r*$ denote the equilibrium process R&D investment of the N firm in the

[5] To obtain a positive R&D solution, we assume that the relevant upper bound of F is $\left\{\frac{2[a - w\alpha(0)] - s(a - w_L\beta)}{4 - s^2}\right\}^2$. This assumption is consistent with $\pi(r = 0) > 0$.

absence of product R&D. We denote the first-order condition of (5) as $f(r^*, w)$. The equilibrium process R&D satisfies

$$f(r^*,w) = -4w\alpha'(r^*)\frac{2[a - w\alpha(r^*)] - s(a - w_L\beta)}{(4-s^2)^2} - Z'(r^*) = 0 \quad (6)$$

We also assume that the second-order condition for the maximization problem is satisfied, i.e.,

$$\frac{-4w}{(4-s^2)^2}\left\{\alpha''(r^*)[2(a - w\alpha(r)) - s(a - w_L\beta)] - 2w[\alpha'(r^*)]^2\right\} - Z''(r^*) < 0 \quad (7)^6$$

Now consider the impact of outsourcing on the N firm's R&D activities when that firm's entry mode is changed from exporting to outsourcing. If outsourcing occurs, the N firm shifts the production from the developed country to the developing country. Accordingly, the wage rate is reduced from w to w_L. Expression (6) may be analyzed to determine the impact of outsourcing on the amount of equilibrium process R&D. Taking second-order derivatives shows that[7]

$$\frac{dr^*}{dw} > 0 \qquad \text{when} \quad a > \frac{4w\alpha(r^*) + sw_L\beta)}{2+s} \qquad (8)$$

As shown in (8), the equilibrium process R&D investment of the multinational firm is positively related to the wage rate in large markets.[8] We thus have the following proposition.

Proposition 1: Outsourcing decreases the process R&D of the multinational firm

---

[6] Further, we assume that $Z''(r^*) > d_1$ to guarantee that the second-order condition for process R&D holds, where $d_1 = \frac{4w}{(4-s^2)^2}\left\{2w[\alpha'(r^*)]^2 - \alpha''(r^*)[2(a - w\alpha(r)) - s(a - w_L\beta)]\right\}$.

[7] See Appendix A for proof.

[8] The intercept term of the inverse demand function is the proxy for market size.

in large markets when it only conducts process R&D.

The above results can be explained as follows. There are two effects of outsourcing on the process R&D of the N firm. First, given the N firm's output, outsourcing reduces its marginal increase in the N firm's output from process R&D. As the N firm's output is positively related to a, larger a implies a larger output of the N firm, which leads to a larger reduction in the total benefit from process R&D investment. Second, given the marginal increase in the N firm's output from process R&D investment, outsourcing increases the N firm's output, thereby enhancing the benefit from process R&D investment. The first effect dominates when the market size is large. Hence, outsourcing reduces the N firm's process R&D investment in large markets. From this aspect, outsourcing and process innovation can be thought of as two substitutes to reduce production cost. As outsourcing occurs, the wage rate reduction due to outsourcing decreases the N firm's incentive to invest in further cost reduction.

The above results can also be understood in terms of the own elasticity of labor demand. With linear labor demand curves as shown in equation (3), the own elasticity of labor demand of the N firm is given by $e_w = \frac{\partial q_1}{\partial w}\frac{w}{q_1}$.

By the envelope theorem, the first-order condition of (5) can be written as

$$f(r^*, w) = 2q_1 * \frac{\partial q_1 *}{\partial r} - Z'(r^*) = 0 \qquad (9)$$

Taking partial derivative of f with respect to w, we have

$$\frac{\partial f}{\partial w} = \frac{-4w\alpha'(r^*)}{(4-s^2)^2}(e+1) \qquad (10)$$

Thus, we have $\frac{\partial f}{\partial w} > 0$ if $-1 < e < 0$ and $\frac{\partial f}{\partial w} < 0$ if $e < -1$. Note that the second-order condition for the N firm's profit maximization is satisfied; thus, we have $\frac{\partial f}{\partial r} < 0$. Hence we get $\frac{dr^*}{dw} > 0$ if $-1 < e < 0$ and if $\frac{dr^*}{dw} < 0$ if $e < -1$.

The above result holds for the following reason. Outsourcing has two different effects on the marginal benefit of process R&D of the N firm. On the one hand it increases the N firm's output (q_1^*). On the other hand, it decreases the marginal increase in the N firm's output from process R&D ($\frac{\partial q_1^*}{\partial r}$). When the own elasticity of labor demand of the N firm is inelastic ($-1 < e < 0$), the wage rate reduction due to outsourcing leads to a small increase in the N firm's output. Thus, the second effect dominates and the net benefit from process R&D will be reduced. Therefore, outsourcing leads to a reduction of the N firm's process R&D investment.

3. The impact of outsourcing with both product R&D and process R&D

In section 2 we analyze the scenario when the N firm only conducts process innovations under both exporting and outsourcing. By making this assumption, we have eliminated the possibility of gaining profits through improving the quality of the firm's products. In this section we extend the current model and allow both product R&D and process R&D to affect firm profitability. Whereas process R&D could increase a firm's profit by lowering marginal cost, product R&D could increase a firm's profit by increasing the degree of product differentiation. Note that an increase

in the degree of product differentiation (a decline in s) shifts the demand curve for the N firm outward. Thus we have $s'(R) < 0$, where R is the N firm's product R&D investment. We also assume $s''(R) \leq 0$. Let G and $K(R)$ denote the fixed costs and variable costs of the N firm's product R&D investment respectively, with $K' > 0$ and $K'' > 0$.[9]

The three-stage game proceeds as follows. The N firm chooses product R&D investment in the first stage and chooses process R&D investment in the second stage. Firms compete in quantities, and profits are realized in the third stage.

First consider the case under exporting. Let $q_1{**}$ and $q_2{**}$ denote the optimal quantities of the N firm and the S firm in the production stage in the presence of product R&D. We have

$$q_1{**} = \frac{2[a - w\alpha(r)] - s(R)(a - w_L\beta)}{4 - s(R)^2} \tag{11}$$

$$q_2{**} = \frac{2[a - w_L\beta] - s(R)[a - w\alpha(r)]}{4 - s(R)^2} \tag{12}$$

Through backward induction, the N firm's maximization problem in the second stage is

$$\underset{r}{Max}\left\{\frac{2[a - w\alpha(r)] - s(R)(a - w_L\beta)}{4 - s(R)^2}\right\}^2 - F - Z(r) \tag{13}$$

Let $r{**}$ denote the N firm's equilibrium process R&D investment in the presence of product R&D and $R{**}$ denote the N firm's equilibrium product R&D investment. We denote the first-order condition of (13) as $g(r{**}, R{**}, w)$. The

[9] For the same reason as we discussed in footnote 2, we assume that G is large enough so that only the multinational firm finds it profitable to undertake product R&D.

equilibrium process R&D satisfies:

$$g(r^{**},w) = -4w\alpha'(r^{**})\frac{2[a - w\alpha(r^{**})] - s(R)(a - w_L\beta)}{[4 - s(R)^2]^2} - Z'(r^{**}) = 0 \quad (14)$$

Taking second-order derivatives shows that $\frac{dr^{**}}{dw} > 0$.[10]

Working back to the first stage of the game, the N firm decides the product R&D investment and its maximization problem is

$$\underset{R}{Max}\left[\frac{2a - 2w\alpha(r) - s(R)(a - w_L\beta)}{4 - s(R)^2}\right]^2 - G - K(R) \quad (15)$$

Let R^{**} denote the N firm's equilibrium product R&D investment. Denote the first-order condition of (13) as $h(R^{**}, r(R^{**}, w), w)$. The equilibrium product R&D satisfies

$$\begin{aligned} &h(R^{**}, r(R^{**}, w), w) \\ &= [2a - 2w\alpha(r) - s(R^{**})(a - w_L\beta)]s'(R^{**})[4 - s(R^{**})^2]^{-3} \\ &\left\{-2(a - w_L\beta)s(R^{**})^2 + 8[a - w\alpha(r)]s(R^{**}) - 8(a - w_L\beta)\right\} - K'(R^{**}) = 0 \end{aligned} \quad (16)$$

We also assume that the second-order condition for the maximization problem is satisfied.[11]

Differentiation of (16) with respect to w yields

$$\frac{\partial h}{\partial R^{**}}\frac{dR^{**}}{dw} + \frac{\partial h}{\partial r}\frac{\partial r}{\partial R^{**}}\frac{dR^{**}}{dw} + \frac{\partial h}{\partial r}\frac{dr}{dw} + \frac{\partial h}{\partial w} = 0 \quad (17)$$

Thus we have

$$\frac{dR^{**}}{dw} = \frac{-\frac{\partial h}{\partial r}\frac{dr}{dw} - \frac{\partial h}{\partial w}}{\frac{\partial h}{\partial R^{**}} + \frac{\partial h}{\partial r}\frac{\partial r}{\partial R^{**}}} \quad (18)$$

[10] The proof is similar to that in Appendix A.

[11] To save space we do not list the second-order condition for the maximization problem, which is a very complicated expression. It is available upon request.

As shown in appendix B, $\frac{\partial h}{\partial w} < 0$ and $\frac{\partial h}{\partial r} > 0$ for $s(R^{**}) < s_1$.[12] Hence we have: (i) $\frac{dR^{**}}{dw} < 0$ if the direct effect of outsourcing dominates the indirect effect of outsourcing for $s(R^{**}) < s_1$; (ii) the sign of $\frac{dR^{**}}{dw}$ remains undetermined otherwise. This leads to the following proposition.

Proposition 2: Outsourcing increases the multinational firm's product R&D provided that the direct effect of outsourcing dominates the indirect effect of outsourcing for $s(R^{**}) < s_1$; the impact of outsourcing on product R&D remains undetermined otherwise.

The logic for these results is as follows. The N firm obtains duopoly profit when s is 1, while it obtains monopoly profit when s is 0. The lower is s, the higher is the N firm's profit and output. Therefore, its incentive for further reduction in s is also higher. Outsourcing affects the product R&D of the N firm through two channels: the direct effect on the product R&D and the indirect effect by affecting the N firm's process R&D. For the direct effect, lower wage rate due to outsourcing increases the N firm's output and market share, which enhances the marginal benefit from product R&D. Hence outsourcing strengthens the benefit from product R&D. From this aspect outsourcing and product innovation can be thought of two complements. In consequence, the N firm's product R&D will be increased. For the indirect effect, as

[12] As shown in appendix B, $s_1 = \frac{4[a - w\alpha(r)] - 2\sqrt{4[a - w\alpha(r)]^2 - 3(a - w_L\beta)^2}}{3(a - w_L\beta)}$. In this paper we focus on the case where the products of the N and the S firm are not very similar i.e. the original level of product differentiation s is less than s_1.

shown in Appendix B, $\frac{\partial h}{\partial r} > 0$ when $s(R^{**}) < s_1$. This implies that an increase in the N firm's process R&D raises the marginal benefit from the product R&D in the product market. Following proposition 1, outsourcing reduces the N firm's process R&D, which in turn reduces the marginal benefit from product R&D. Hence the indirect effect of outsourcing by affecting the N firm's process R&D is negative. Therefore outsourcing increases the N firm's product R&D when we only consider the direct effect of outsourcing on product R&D. Due to the interaction between product R&D and process R&D, the impact of outsourcing remains undetermined when we also consider indirect effect of outsourcing through process R&D. The direct effect of outsourcing dominates when $\frac{\partial h}{\partial r}\frac{dr}{dw} < -\frac{\partial h}{\partial w}$. [13]

4. Numerical analysis

We will use the following parametric functions to illustrate the above results:

Assume that $\alpha(r) = \alpha - r^2$, $Z(r) = \frac{r^2}{2}$, $s(R) = \bar{s} - R$, $K(R) = \frac{R^2}{2}$, $w_L = 1$ and $w > 1$. All of our assumptions are satisfied.

4.1 With only process R&D

[13] The above results can also be understood in terms of the S firm's best response with respect to the N firm's output. Please see Appendix C for proof.

We have $q_1^* = \dfrac{2(a - w\alpha + wr^2) - s(a-\beta)}{4 - s^2}$.

From $f(r^*, w) = 0$, we obtain

$$r^* = \sqrt{\frac{(4-s^2)^2}{16w^2} - \frac{(2-s)a + s\beta}{2w} + \alpha}\ .$$

Hence we have

$$\frac{dr^*}{dw} = \frac{w^{-3}}{16}\left[\frac{(4-s^2)^2}{16w^2} - \frac{(2-s)a+s\beta}{2w} + \alpha\right]^{-\frac{1}{2}}\left[4(2-s)aw + 4s\beta w - (4-s^2)^2 + 8w^3\right]$$

Therefore $\dfrac{dr^*}{dw} > 0$ if $a > \dfrac{(4-s^2)^2 - 8w^3 - 4s\beta w}{4(2-s)w}$.

4.2 With both product R&D and process R&D

When the N firm conducts both product R&D and process R&D, with the above parametric functions we obtain

$$r^{**} = \sqrt{\frac{[4-(\bar{s}-R)^2]^2}{16w^2} - \frac{(2-\bar{s}+R)a + (\bar{s}-R)\beta}{2w} + \alpha}\ .$$

From $h(R^{**}, r(R^{**}, w), w) = 0$, it can be shown that

(i) $\dfrac{dR^{**}}{dw} < 0$ if $s(R^{**}) < s_1'$; (ii) the sign of $\dfrac{dR^{**}}{dw}$ is undetermined otherwise.[14]

5. Welfare impacts of outsourcing

We next study the welfare implications of R&D investment in the presence of international outsourcing and examine whether there exist different externality effects for firms that only undertake process R&D and those that undertake both

[14] See Appendix D for proof.

product R&D and process R&D. For this purpose we compare the optimal R&D level from the firm's perspective and that from an overall efficiency perspective.

5.1 With only process R&D

The total welfare of the society is defined as the sum of the N firm's profit, the S firm's profit, and consumer utility. Let W_r denote the total welfare of the society when the N firm only undertakes process R&D. Thus W_r is given by

$$W_r = \pi_1 + \pi_2 + U = q_1{}^{*2} - F - Z(r) + q_2{}^{*2} + a(q_1{}^* + q_2{}^*) - \frac{q_1{}^{*2} + q_2{}^{*2}}{2} - sq_1{}^* q_2{}^* \quad (19)$$

By the envelope theorem, we have

$$\begin{aligned} \frac{dW_r}{dr} &= \frac{d\pi_1}{dr} + \frac{d\pi_2}{dr} + \frac{dU}{dr} \\ &= \frac{\partial \pi_1}{\partial r} + \frac{\partial \pi_1}{\partial q_2}\frac{\partial q_2}{\partial r} + \frac{\partial \pi_2}{\partial q_1}\frac{\partial q_1}{\partial r} + \frac{\partial U}{\partial q_1}\frac{\partial q_1}{\partial r} + \frac{\partial U}{\partial q_2}\frac{\partial q_2}{\partial r} \end{aligned} \quad (20)$$

An increase in r has several conflicting effects on the total welfare. First, the direct effect on the N firm's profit (captured by the first term of equation (20)) is negative, because an increase in process R&D increases the N firm's R&D cost. Second, the strategic effect on the N firm's profit (captured by the first term of equation (20)) is positive, as the N firm's process R&D reduces the S firm's output, thereby increasing the N firm's profit. Third, as process R&D of the N firm only reduces its own production cost, it has a negative effect on the S firm's profit (captured by the third term of equation (20)). Fourth, it affects consumer utility through the output of the N firm and the S firm. As an increase in process R&D of the N firm increases its own output but reduces the S firm's output, the net impact on

consumer utility is undetermined.

By simplifying equation (18), we find that the optimal process R&D satisfies

$$\frac{dW_r}{dr}(r=r_W)=-4w\alpha'(r_W)\frac{(3s^2-12s+12)a-(5s^2+4)w\alpha(r_W)]-(s^3+4s)w_L\beta}{[4-s^2]^2}-Z'(r_W)=0 \quad (21)$$

Note that $r*$ is the equilibrium process R&D investment of the N firm in the absence of product R&D. Thus we get

$$\begin{aligned}&\frac{dW_r}{dr}(r=r^*)=-4w\alpha'(r^*)\frac{(3s^2-12s+12)a-(5s^2+4)w\alpha(r^*)]-(s^3+4s)w_L\beta}{[4-s^2]^2}-Z'(r^*)\\&>-4w\alpha'(r^*)\frac{2[a-w\alpha(r^*)]-s(a-w_L\beta)}{(4-s^2)^2}-Z'(r^*)=0\end{aligned} \quad (22)$$

if $(3s^2-8s+4)a-(5s^2+4)w\alpha(r^*)+(s^3+4s)w_L\beta>0$

Therefore we find that the social optimal process R&D level is greater than the N firm's equilibrium process R&D investment that maximizes its own profit when the market size is large.

5.2 With both product R&D and process R&D

Let W_R denote the total welfare of the society when the N firm undertakes both product R&D and process R&D. Thus we have

$$\begin{aligned}&\frac{dW_R}{dR}=\frac{d\pi_1}{dR}+\frac{d\pi_2}{dR}+\frac{dU}{dR}\\&=\frac{\partial\pi_1}{\partial s}s'(R)+\frac{\partial\pi_1}{\partial q_2}\frac{\partial q_2}{\partial s}s'(R)+\frac{\partial\pi_2}{\partial s}s'(R)+\frac{\partial\pi_1}{\partial q_1}\frac{\partial q_1}{\partial s}s'(R)+\frac{\partial U}{\partial q_1}\frac{\partial q_1}{\partial s}s'(R)+\frac{\partial U}{\partial q_2}\frac{\partial q_1}{\partial s}s'(R)+\frac{\partial U}{\partial s}s'(R)\end{aligned} \quad (23)$$

An increase in R has several effects on the total welfare. First, the direct effect on the N firm's profit (captured by the first term of equation (23)) is positive, because an increase in product R&D (an increase in the degree of product differentiation) shifts its own demand curve outward. The strategic effect on the N firm's profit (captured

by the second term of equation (23)) is negative, because an increase in the degree of product differentiation also shifts the S firm's demand curve outward. Similarly, the direct effect on the S firm's profit is positive and the strategic effect on the S firm's profit is negative. Third, it has direct and indirect effects on consumer utility. The direct effect is positive (captured by the last term of equation (23)). The indirect effect is positive as well (captured by the fifth and sixth term of equation (23)), because an increase in the degree of product differentiation enhances the output of both the N firm and the S firm.

Note that R^{**} denotes the N firm's equilibrium product R&D investment when it undertakes both product R&D and process R&D.

$$\frac{dW_R}{dR}(R=R^{**})=\frac{d\pi_2}{dR}(R=R^{**})+\frac{dU}{dR}(R=R^{**}) \quad (24)$$

As the first term of equation (24) is positive if the direct effect of an increase in the degree of product differentiation on the S firm's profit dominates the strategic effect and the second term of equation (24) is positive, we find that the social optimal product R&D level is greater than the N firm's equilibrium product R&D investment that maximizes its own profit.

This result can be understood by the externality effect of product R&D investment. In contrast to process R&D, which only affects the production costs of the investing firm, product differentiation by one firm also enhances demand for the other firm's product and consumer utility; hence, there exists positive inter-firm spillover from product R&D investment. Therefore, we find that outsourcing leads to a larger increase in welfare in industries with predominantly product R&D investment than in

those with process, predominantly firm-specific process, R&D investment. Our finding is consistent with the conventional wisdom that the existence of such externality leads to the underinvestment of product R&D of MNCs.

6. Summary and Conclusions

In this paper, we develop a model to illustrate the effects of international outsourcing of production on the volume and composition of the home country's research and development. Our analysis yields several interesting results. First, outsourcing reduces process R&D in large markets if the multinational firm only conducts process R&D. Second, outsourcing promotes product R&D but tends to discourage process R&D if the multinational firm conducts both product R&D and process R&D when we only consider the direct impact of outsourcing on the composition of R&D. Therefore, outsourcing tends to emerge as a complementary factor to product development but as a substitute for process R&D. Our analysis implies that international outsourcing has a different effect on product innovation and process innovation.

As is evident from these results, our model provides rich predictions about the volume and compositions of multinational firms' R&D. It should also help in designing related empirical studies.

In this paper we only consider the outsourcing of production and have assumed that the cost of R&D does not change with outsourcing. One promising avenue for

future research is to extend the analysis to examine the outsourcing R&D activities to developing countries, which will change firms' incentives for R&D. The effects of different types of product market competition, such as Bertrand competition, are also worth studying. The insights developed in this paper should be useful for pursuing related lines of inquiry.

References

Almeida, P., 1996. Knowledge sourcing by foreign multinationals: patent citation analysis in the US semiconductor industry. Strategic Management Journal 17, 155–165.

Antràs, P., Helpman, E., 2004. Global Sourcing. Journal of Political Economy 112, 552-580.

Bandyopadhyay, S., Wall, H., 2010. Immigration and Outsourcing: A General Equilibrium Analysis Review of Development Economics 14, 433-446.

Becker, S.O., Ekholm, K., Muendler, M.A., 2008. Offshoring and the Onshore Composition of Occupations, Tasks and Skills. CEPR working paper.

Che, X., Yang, Y., Zhang, H., 2010. Outsourcing and R&D Investment with Costly Patent Protection. Working paper.

Chen, Y., Ishikawa, J., Yu, Z., 2004. Trade Liberalization and Strategic Outsourcing. Journal of International Economics 63, 419-436.

Chen, Y., Sen, D., 2010. Upstream Outsourcing, Economies of Scale, and Incentives for Downstream R&D. Working paper.

Cohen, W.M., Klepper, S., 1996. Firm size and the nature of innovation within industries: The case of process and product R&D. Review of Economics and Statistics 78, 232-243.

Feenstra, R.C., Hanson, G. H., 1999. The impact of outsourcing and high-technology capital on wages: estimates for the United States 1979 – 1990. Quarterly Journal of Economics 114, 907–940.

Fink, C., Maskus, E. K., 2004. Intellectual Property and Development: Lessons from Recent Economic Research. Oxford: Oxford University Press and World Bank.

Frost, T.S., 2001. The Geographic Sources of Foreign Subsidiaries' Innovations. Strategic Management Journal 22, 101–123.

Grossman, G.M., Helpman, E., 2002. Integration versus outsourcing in industry equilibrium. Quarterly Journal of Economics 117, 58–119.

Hijzen, A., Görg, H., Hine, R.C., 2005. International outsourcing and the skill structure of labor demand in the United Kingdom. The Economic Journal 115,

860–878.

Imai, K., 1992. The Japanese pattern of innovation and its evolution. In: Rosenberg, N., Laudan, R., Mowery, D. (Eds.), Technology and The Wealth of Nations. Stanford University Press, Stanford.

Jones, R.W., 2005. Immigration vs. outsourcing: effects on labor markets. International Review of Economics and Finance 14, 105–114.

Lin, P., Saggi, K., 2002. Product differentiation, process R&D, and the nature of market competition. European Economic Review 46, 201-211.

Mansfield, E., 1981. Composition of R&D expenditures: Relationship to size of firm, concentration, and innovative output. Review of Economics and Statistics 63, 610-615.

Marjit, S., Mukherjee, A., 2008. International Outsourcing and R&D: Long run Implications for Consumers. Review of International Economics 16, 1010-1022.

Mukherjee, A., Dinda, S., 2010. International Outsourcing, Tax and Patent Protection. Journal of Public Economic Theory, forthcoming.

Mukherjee, A., Ray, A., 2007. Strategic Outsourcing and R&D in a Vertical Structure. The Manchester School 75, 297-310.

Mukherjee, A., Tsai, Y. International outsourcing and welfare reduction: an entry deterrence story. The Manchester School, forthcoming.

Rosenkranz, S., 2003. Simultaneous choice of process and product innovation when consumers have a preference for product variety. Journal of Economic Behavior & Organization 50, 183-201.

Shaked, A., Sutton, J., 1982. Relaxing Price Competition through Product Differentiation. *Review of Economic Studies* 49, 3-13.

Shaked, A., Sutton, J., 1982. Natural Oligopolies,. *Econometrica* 51, 1469-1483.

Singh, J., 2007. Asymmetry of knowledge spillovers between MNCs and host country firms. Journal of International Business Studies 38, 764–786.

Tirole, J., 1988. The Theory of Industrial Organization. The MIT Press, Cambridge.

Appendix A: Proof of proposition 1

From equation (6), we have

$$f(r^*,w) = -4w\alpha'(r^*)\frac{2[a-w\alpha(r^*)]-s(a-w_L\beta)}{(4-s^2)^2} - Z'(r^*) = 0$$

Taking partial derivative of *f* with respect to w and r^* respectively, we have

$$\frac{\partial f}{\partial w} = \frac{-4\alpha'(r^*)}{(4-s^2)^2}[2a-4w\alpha(r^*)-s(a-w_L\beta)].$$

Thus $\frac{\partial f}{\partial w} > 0$ if $a > \frac{4w\alpha(r^*)-s(a-w_L\beta)}{2}$.

$$\frac{\partial f}{\partial r^*} = \frac{-4w}{(4-s^2)^2}\left\{\alpha''(r^*)[2(a-w\alpha(r^*))-s(a-w_L\beta)]-2w[\alpha'(r^*)]^2\right\} - Z''(r^*).$$

From (7), we get $\frac{\partial f}{\partial r^*} < 0$. Hence, we have

$$\frac{dr^*}{dw} = -\frac{\frac{\partial f}{\partial w}}{\frac{\partial f}{\partial r^*}} > 0 \quad \text{when} \quad a > \frac{4w\alpha(r^*)-s(a-w_L\beta)}{2}$$

Appendix B: Proof of proposition 2.

From equation (14), we have

$$\begin{aligned}
&h(R^{**}, r(R^{**},w), w) \\
&= [2a-2w\alpha(r)-s(R^{**})(a-w_L\beta)]s'(R^{**})[4-s(R^{**})^2]^{-3} \\
&\left\{-2(a-w_L\beta)s(R^{**})^2 + 8[a-w\alpha(r)]s(R^{**}) - 8(a-w_L\beta)\right\} - K'(R^{**}) = 0
\end{aligned}$$

Differentiation the above equation with respect to w yields:

$$\frac{\partial h}{\partial R^{**}}\frac{dR^{**}}{dw} + \frac{\partial h}{\partial r}\frac{\partial r}{\partial R^{**}}\frac{dR^{**}}{dw} + \frac{\partial h}{\partial r}\frac{dr}{dw} + \frac{\partial h}{\partial w} = 0$$

Hence we have

$$\frac{dR^{**}}{dw} = \frac{-\frac{\partial h}{\partial r}\frac{dr}{dw} - \frac{\partial h}{\partial w}}{\frac{\partial h}{\partial R^{**}} + \frac{\partial h}{\partial r}\frac{\partial r}{\partial R^{**}}}$$

As the second order condition is satisfied, we have $\frac{\partial h}{\partial R^{**}} < 0$.

From the proof in Appendix A, we have $\frac{dr}{dw} > 0$ when the market size is large.

$\frac{\partial h}{\partial w} = -4\alpha(r)s'(R^{**})[4-s(R^{**})^2]^{-3}\left\{-3(a-w_L\beta)s(R^{**})^2 + 8[a-w\alpha(r)]s(R^{**}) - 4(a-w_L\beta)\right\}$ and

$\frac{\partial h}{\partial r} = -4w\alpha'(r)s'(R^{**})[4-s(R^{**})^2]^{-3}\left\{-3(a-w_L\beta)s(R^{**})^2 + 8[a-w\alpha(r)]s(R^{**}) - 4(a-w_L\beta)\right\}$.

Therefore $\frac{\partial h}{\partial w} < 0$ and $\frac{\partial h}{\partial r} > 0$ for $s(R^{**}) < s_1$, where

$$s_1 = \frac{4[a-w\alpha(r)] - 2\sqrt{4[a-w\alpha(r)]^2 - 3(a-w_L\beta)^2}}{3(a-w_L\beta)}.$$

From $g(r^{**}, R^{**}, w) = -4w\alpha'(r^{**})\frac{2[a-w\alpha(r^{**})] - s(R^{**})(a-w_L\beta)}{[4-s(R^{**})^2]^2} - Z'(r^{**}) = 0$

We have $\frac{dg}{dR^{**}} = \frac{\partial g}{\partial r}\frac{\partial r}{\partial R^{**}} + \frac{\partial g}{\partial R^{**}} = 0$

Thus we get $\frac{dr}{dR^{**}} = -\frac{\frac{\partial g}{\partial R^{**}}}{\frac{\partial g}{\partial r}}$

Note that $\frac{\partial g}{\partial r} < 0$ as the second order condition is satisfied.

$$\frac{\partial g}{\partial R^{**}} =$$

$$-s'(R^{**})[4-s(R^{**})^2]^{-3}\left\{3(a-w_L\beta)s(R^{**})^2 - 8[a-w\alpha(r)]s(R^{**}) + 4(a-w_L\beta)\right\}$$

Hence we find that

$$\frac{\partial g}{\partial R^{**}} > 0 \text{ and } \frac{\partial r}{\partial R^{**}} = -\frac{\frac{\partial g}{\partial R^{**}}}{\frac{\partial g}{\partial r}} > 0 \text{ for } s(R^{**}) < s_1.$$

In principle an increase in R has two effects on h. First, due to the diminishing return of product R&D investment, we have $\frac{\partial h}{\partial R^{**}} < 0$. Second, an increase in R leads to the increase in process R&D, which in turn enhances the marginal benefit from product R&D. To focus on the impact of outsourcing on product R&D, in this paper we focus on the case when the direct effect dominates the indirect effect (that

is $\left|\frac{\partial h}{\partial R**}\right| > \left|\frac{\partial h}{\partial r}\frac{\partial r}{\partial R**}\right|$).

Therefore we find that an increase in w has two effects on the equilibrium product R&D. The direct effect (captured by $-\frac{\partial h}{\partial w}$) is negative while the indirect effect through the impact on process R&D (captured by $-\frac{\partial h}{\partial r}\frac{dr}{dw}$) is positive. We get

$\frac{dR**}{dw} = \frac{-\frac{\partial h}{\partial r}\frac{dr}{dw} - \frac{\partial h}{\partial w}}{\frac{\partial h}{\partial R**} + \frac{\partial h}{\partial r}\frac{\partial r}{\partial R**}} < 0$ when the direct effect of outsourcing outweighs the indirect effect for $s(R**) < s_1$.

Appendix C: Proof of the impact of the S firm's best response with respect to the N firm's output on the N firm's Product R&D.

The S firm's best response with respect to the N firm's output on the N firm's output also affects the equilibrium Product R&D of the N firm. Given the N firm's product and process R&D investment, the strategic effect of outsourcing on the S firm's output can be captured by $\frac{\partial h}{\partial w}$.

The first-order condition of the N firm's profit maximization problem in the first stage can be rewritten as $h(q_1, q_2(q_1), w) = 0$.

By total differentiation, we have

$$\frac{\partial h}{\partial q_1}dq_1 + \frac{\partial h}{\partial q_2}\frac{dq_2}{dq_1}dq_1 + \frac{\partial h}{\partial w}dw = 0$$

Thus we get $\frac{\partial h}{\partial w} = -(\frac{\partial h}{\partial q_1} + \frac{\partial h}{\partial q_2}\frac{dq_2}{dq_1})\frac{dq_1}{dw}$

Note that, $\frac{\partial h}{\partial q_1} < 0$ as the second order condition is satisfied. For Cournot

completion, we have $\frac{\partial h}{\partial q_2} < 0$. We also have $\frac{dq_1}{dw} < 0$ and $\frac{dq_2}{dq_1} < 0$.

To guarantee that there is only one equilibrium, we also have $\left|\frac{\partial h}{\partial q_2}\right| < \left|\frac{\partial h}{\partial q_1}\right|$

Therefore we find that $\frac{\partial h}{\partial w} < 0$ if $\left|\frac{dq_2}{dq_1}\right| < 1$ and the sign of $\frac{\partial h}{\partial w}$ is undetermined otherwise.

Appendix D: Numerical analysis

Assume $\alpha(r) = \alpha - r^2$, $Z(r) = \frac{r^2}{2}$, $s(R) = \bar{s} - R$, $K(R) = \frac{R^2}{2}$, $w_L = 1$ and $w > 1$. All of our assumptions are satisfied. We thus have

$$\frac{\partial h}{\partial w} = 4(\alpha - r^2)[4-(\bar{s}-R^{**})^2]^{-3}\left\{-3(a-\beta)(\bar{s}-R^{**})^2 + 8[a - w(\alpha - r^2)](\bar{s}-R^{**}) - 4(a-\beta)\right\}$$

$$\frac{\partial h}{\partial r} = -8wr[4-(\bar{s}-R^{**})^2]^{-3}\left\{-3(a-\beta)(\bar{s}-R^{**})^2 + 8[a - w(\alpha - r^2)](\bar{s}-R^{**}) - 4(a-\beta)\right\}.$$

Therefore, $\frac{\partial h}{\partial w} < 0$ and $\frac{\partial h}{\partial r} > 0$ for $s(R^{**}) < s_1'$, where

$$s_1' = \frac{4[a - w(\alpha - r^2)] - 2\sqrt{4[a - w(\alpha - r^2)]^2 - 3(a-\beta)^2}}{3(a - w\beta)}.$$

We also have

$$\frac{dr^{**}}{dw} = \frac{w^{-3}}{16}\left[\frac{(4-s^2)^2}{16w^2} - \frac{(2-s)a + s\beta}{2w} + \alpha\right]^{-\frac{1}{2}}\left[4(2-s)aw + 4s\beta w - (4-s^2)^2 + 8w^3\right]$$

Therefore $\frac{dR^{**}}{dw} = \frac{-\frac{\partial h}{\partial r}\frac{dr}{dw} - \frac{\partial h}{\partial w}}{\frac{\partial h}{\partial R^*} + \frac{\partial h}{\partial r}\frac{\partial r}{\partial R^{**}}} < 0$ for $s < s_1'$, and the sign of $\frac{dR^{**}}{dw}$ remains undermined otherwise.

Appendix E: The effect of outsourcing on R&D with vertical differentiations

In this section we study the impact of outsourcing in a vertically differentiated product space. Let the consumer's preference be described as $U = \theta v - p$ if the consumer consumes one unit of quality s and pays price p, and by 0 otherwise. The parameter θ of taste for quality is uniformly distributed across the population of consumers between $\underline{\theta} \geq 0$ and $\overline{\theta} = \underline{\theta} + 1$. The density is 1 (Tirole, 1988).

Suppose the N firm and the S firm produce good 1 to good 2 respectively. Let v_1 and v_2 denote the quality of good 1 to good 2, where $v_1 > v_2$. A consumer with parameter θ prefers good 1 to good 2 if $\theta v_1 - p_1 \geq \theta v_2 - p_2$. Let's denote $\tilde{\theta} = \frac{p_1 - p_2}{v_1 - v_2}$ and $\Delta v = v_1 - v_2$. We also assume $\frac{p_1}{v_1} > \underline{\theta}$, which means each consumer will buy one unit of a good either from the N firm or the S firm. This yields the following demand functions:

$$D_1(p_1, p_2) = \overline{\theta} - \tilde{\theta} \quad D_2(p_1, p_2) = \tilde{\theta} - \underline{\theta}.$$

Similar to our previous discussion, we assume that the fixed costs of product R&D is so large that it is not profitable for the S firm to invest in R&D.

E.1 With only process R&D

When the N firm only conducts process R&D, the marginal production costs of the N firm and the S firm are $w\alpha(r)$ and $w_L\beta$ respectively. Suppose F and $Z(r)$ denote the fixed costs and the variable costs respectively of process R&D. Now consider a two-stage game: in the first stage, the N firm chooses process R&D; in the

second stage, both firms compete in prices, and profits are realized. We solve the game through backward induction.

The maximization problems in the second stage are

$$\underset{p_1}{Max}(p_1 - w\alpha(r))D_1(p_1, p_2)$$

$$\underset{p_2}{Max}(p_2 - w_L\beta)D_2(p_1, p_2)$$

The optimal prices chosen by each firm are derived by solving the first-order conditions of the above equations, which yields

$$p_1 = \frac{1}{3}[(2\overline{\theta} - \underline{\theta})\Delta v + 2w\alpha(r) + w_L\beta]$$

$$p_2 = \frac{1}{3}[(\overline{\theta} - 2\underline{\theta})\Delta v + w\alpha(r) + 2w_L\beta]$$

The equilibrium profit of the N firm is given by

$$\pi_1 = \frac{1}{9\Delta v}[(2\overline{\theta} - \underline{\theta})\Delta v + w_L\beta - w\alpha(r)]^2 - F - z(r)$$

Let $r*$ denote the equilibrium process R&D investment of the N firm in the absence of product R&D. We denote the first-order condition of (5) as $f(r*, w)$. The N firm's equilibrium process R&D satisfies

$$f(r*, w) = \frac{2}{9(\Delta v)^2}[(2\overline{\theta} - \underline{\theta})\Delta v + w_L\beta - w\alpha(r*)][-w\alpha'(r*)] - Z'(r*) = 0$$

Taking partial derivative of f with respect to w, we have

$$\frac{\partial f}{\partial w} = \frac{-2\alpha'(r*)}{9\Delta v}[(2\overline{\theta} - \underline{\theta})\Delta v + w_L\beta - w\alpha(r*)].$$

Thus $\frac{\partial f}{\partial w} > 0$ if $(2\overline{\theta} - \underline{\theta})\Delta v + w_L\beta - w\alpha(r*) > 0$.

$$\frac{dr*}{dw} = -\frac{\frac{\partial f}{\partial w}}{\frac{\partial f}{\partial r*}} > 0 \quad \text{when} \quad (2\overline{\theta} - \underline{\theta})\Delta v + w_L\beta - w\alpha(r*) > 0.$$

Therefore, we find that outsourcing decreases the process R&D of the multinational firm when it only conducts process R&D when $(2\overline{\theta}-\underline{\theta})\Delta v + w_L\beta - w\alpha(r^*) > 0$.

E.2 With both process R&D and product R&D

When the N firm undertakes both product R&D and process R&D, it can invest in v_1 through quality upgrading. Thus the quality of the N firm's goods is a function of its product R&D. Hence we have $v_1 = v_1(R)$ with $v_1'(R) > 0$.

The three-stage game proceeds as follows. The N firm chooses product R&D investment to determine the quality level of its products in the first stage and chooses process R&D investment in the second stage. Firms compete in quantities, and profits are realized in the third stage.

Through backward induction, the N firm's maximization problem in the second stage is

$$\pi_1 = \frac{1}{9[v_1(R)-v_2]}[(2\overline{\theta}-\underline{\theta})(v_1(R)-v_2)+w_L\beta - w\alpha(r)]^2 - F - z(r)$$

Let r^{**} denote the N firm's equilibrium process R&D investment in the presence of product R&D. We denote the first-order condition of (11) as $g(r^{**},w)$. The equilibrium process R&D satisfies

$$g(r^{**},w) = \frac{2}{9[v_1(R)-v_2]^2}[(2\overline{\theta}-\underline{\theta})(v_1(R)-v_2)+w_L\beta - w\alpha(r^{**})][-w\alpha'(r^{**})] - Z'(r^{**}) = 0$$

Taking second-order derivatives shows that $\frac{dr^{**}}{dw} > 0$ when $(2\overline{\theta}-\underline{\theta})\Delta v + w_L\beta - w\alpha(r^{**}) > 0$.

Working back to the first stage of the game, the N firm decides the product R&D investment and its maximization problem is

$$\underset{R}{Max}\frac{1}{9[v_1(R)-v_2]}[(2\overline{\theta}-\underline{\theta})(v_1(R)-v_2)+w_L\beta-w\alpha(r)]^2-G-K(R)$$

Let R^{**} denote the N firm's equilibrium product R&D investment. Denote the first-order condition of (13) as $h(R^{**},r(R^{**},w),w)$. The equilibrium product R&D satisfies

$$\begin{aligned}&h(R^{**},r(R^{**},w),w)\\&=\frac{1}{9}(2\overline{\theta}-\underline{\theta})^2-\frac{[w_L\beta-w\alpha(r)]^2}{9[v_1(R^{**})-v_2]^2}v_1'(R^{**})-K'(R^{**})=0\end{aligned}$$

We also assume that the second-order condition for the maximization problem is satisfied. Thus we have $\frac{\partial h}{\partial R^{**}}<0$. We also have

$$\frac{\partial h}{\partial r}=\frac{2[w_L\beta-w\alpha(r)]}{9[v_1(R^{**})-v_2]^2}v_1'(R^{**})w\alpha'(r)>0$$

$$\frac{\partial h}{\partial w}=\frac{2[w_L\beta-w\alpha(r)]}{9[v_1(R^{**})-v_2]^2}v_1'(R^{**})\alpha(r)<0$$

From $\frac{dg}{dR^{**}}=\frac{\partial g}{\partial r}\frac{\partial r}{\partial R^{**}}+\frac{\partial g}{\partial R^{**}}=0$

We have $\frac{dr}{dR^{**}}=-\frac{\frac{\partial g}{\partial R^{**}}}{\frac{\partial g}{\partial r}}$

Note that $\frac{\partial g}{\partial r}<0$ as the second order condition is satisfied. We also have

$$\frac{\partial g}{\partial R^{**}}=\frac{2}{9}[-w\alpha'(r)][v_1(R^{**})-v_2]^{-3}v_1'(R^{**})\left\{2[w\alpha(r)-w_L\beta]-(2\overline{\theta}-\underline{\theta})[v_1(R^{**})-v_2]\right\}$$

Thus we have $\frac{\partial g}{\partial R^{**}}>0$ and $\frac{dr}{dR^{**}}>0$ if $2[w\alpha(r)-w_L\beta]>(2\overline{\theta}-\underline{\theta})[v_1(R^{**})-v_2]$.

This implies that the presence of process R&D strengthens the marginal benefit from product R&D if the original quality difference between the N firm and the S firm is small. Similar to appendix B, in this paper we focus on the case when the direct effect R on h dominates the indirect effect ($\left|\frac{\partial h}{\partial R^{**}}\right|>\left|\frac{\partial h}{\partial r}\frac{\partial r}{\partial R^{**}}\right|$).

Hence we get $\frac{dR^{**}}{dw} = \frac{-\frac{\partial h}{\partial r}\frac{dr}{dw} - \frac{\partial h}{\partial w}}{\frac{\partial h}{\partial R^{**}} + \frac{\partial h}{\partial r}\frac{\partial r}{\partial R^{**}}} < 0$ if $\frac{\partial h}{\partial w} < 0$.

We find that outsourcing increases the multinational firm's product R&D provided that the direct effect of outsourcing dominates the indirect effect of outsourcing. The impact of outsourcing on product R&D remains undetermined otherwise. This is similar to proposition 2. Therefore we conclude that the specification of competition in a vertically differentiated market does not change our conclusions.