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## Trade liberalisation, process and product innovation, and relative skill demand

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# Trade Liberalisation, Process and Product Innovation, and Relative Skill Demand

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# Trade Liberalisation, Process and Product Innovation, and Relative Skill Demand

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The interaction between trade liberalisation, product and process innovation, and relative skill demand is analysed in a model of international oligopoly. Lower trading barriers increase the degree of foreign competition. The competing enterprises respond by investing more aggressively in lowering marginal costs of production. Moreover, firms reduce the substitutability of their products through additional investment in product innovation. The paper also shows that the relative demand for skilled workers may increase as a result.

*JEL Classification:* F12, F15, F16, O32

*Keywords:* Intra-industry Trade; Process Innovation; Product Innovation; Relative Skill Demand; Trade Liberalisation

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## 1 Introduction

Data for the USA show that industrial R&D funding has increased sharply in the 1980s and 1990s (see figure 1). In 2004, R&D expenditures of the business sector amounted to 183.9 billion dollars compared to just 52.7 billion in 1979. While the ratio of industrial R&D expenditures to GDP remained fairly constant throughout the 1960s and 1970s, it has risen from at about one per cent in 1979 to 1.43 per cent in 1990 and 1.72 per cent in 2004 (down from 1.90 in 2000).<sup>1</sup> On the contrary, R&D funded by the federal government has grown much more slowly over the same time horizon and even declined when measured as a ratio of GDP. Paralleling the rise in industrial R&D spendings, the US (and other industrialised countries) experienced a breakdown in the relative demand for unskilled workers.<sup>2</sup>

Against this background, the purpose of the present paper is twofold. First, to provide an analysis of the effects of lower trading barriers on the incentives of firms to undertake R&D investment. Second, to explore the subsequent effect on firms' demand for skilled relative to unskilled workers. By doing so, the study provides some insights into the question of whether (i) economic integration might have been a driving force of the large increase in industrial R&D funding and whether (ii) higher investments in R&D may have contributed to the aforementioned developments in the labour market.

Towards this aim, a simple model of international oligopoly is set up. Firms operate in segmented markets and can invest in both process and product innovation. Process innovation allows firms to produce at lower marginal production costs. Product innovation is understood as a means of reducing the substitutability between goods. Therefore, the focus lies on innovation within a given product life-cycle (rather than on the invention of new products). Firms hire skilled workers for performing R&D while production requires solely unskilled workers.<sup>3</sup>

Economic integration is then modelled as a reduction in trading costs between segmented mar-

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<sup>1</sup>Figures are provided by the National Science Foundation and total expenditures are measured in constant 2000 dollars. R&D data for 2004 are projections.

<sup>2</sup>For a recent paper that reviews the ongoing academic debate in this area and provides detailed empirical evidence on trends in U.S. wage inequality see Autor et al. (2005).

<sup>3</sup>One could also assume that R&D is relatively more skill-intensive than production. The extreme assumption of skilled and unskilled workers being the only inputs in R&D and production, respectively, just simplifies the model.

kets. Competitive pressures increase and induce firms to invest more in lower marginal production costs and a greater degree of product differentiation. In fact, investing in one type of R&D also provides additional incentives to invest in the other. Thus, process and product innovations are found to be complementary. Higher investments in R&D raise relative skill demand both directly through higher demand for skilled workers and indirectly through a reduction in the requirements of unskilled workers per unit of production. For conventional functional form assumptions these effects will outweigh the positive effect on the demand for unskilled workers resulting from an increase in total output following trade liberalisation.

There exists a small theoretical literature that focuses on both process and product innovation at the same time. Lin and Saggi (2002) investigate the relationship between process and product R&D in a three stage model. Before production takes place, firms decide first on product R&D and then on the level of process R&D. In contrast, Rosenkranz (2003) analyses the strategic decision of oligopolists that simultaneously choose product and process innovation. Weiss (2003) examines the effect of changes in the degree of competition on firms' decision to engage in either process or product R&D. However, neither the issue of economic integration nor any labour market effects are considered in these studies. Instead of focusing on a single market the present work analyses the effects of a change in the competitive environment on (the interplay of) the two types of innovation in an international oligopoly.

The paper at hand is closer related to studies by Neary (2002) and Haaland and Kind (2004). Neary (2002) demonstrates that a reduction in import barriers will induce firms to increase their strategic investment as to blockade entry of foreign competitors. Assuming investment to be skilled-labour intensive (relative to production), trade liberalisation increases the wage premium of skilled workers as well as skill-intensity. Haaland and Kind (2004) analyse the interaction between trading costs, process innovation and R&D subsidies. Among other things their study illustrates that trade liberalisation may increase private and social incentives to invest in cost-saving R&D.

The present paper shares some similarities with these two studies but crucial differences exist. While Neary (2002) studies the *threat* of import competition into the home market, the focus

of this study is on the decision process of a firm that simultaneously serves the home *and* the foreign market, and on situations, in which intra-industry trade actually occurs. The model abstracts from the strategic value of investment and shows that trade liberalisation increases the *efficiency* of R&D investments. Haaland and Kind (2004), on the other hand, do not consider labour market effects of the interaction between trading costs and R&D investments. More importantly, neither Neary (2002) nor Haaland and Kind (2004) deal with product innovation but concentrate on process innovation. Given the fact that in the USA product R&D appears to be quantitatively more important than process R&D,<sup>4</sup> extending the analysis to incorporate both types of R&D seems to be of great importance.

The rest of the paper is organised as follows. Section 2 presents the basic model. The interaction between trade liberalisation and the incentives of firms to invest in process and product innovation is analysed in section 3. Section 4 then studies the subsequent effects on the relative skill demand of firms. Finally, section 5 offers some concluding remarks and briefly describes how the setting could be implemented into a general equilibrium framework.

## 2 The Basic Model

There are two identical countries, Home (H) and Foreign (F), and two firms. Firm 1 is located in Home, while firm 2 is located in Foreign. Given the symmetry of the model, we shall only present equations for Home. Analogous equations exist for Foreign as well.

Each of the two firms produces a differentiated good. The utility of the representative consumer is a function of the two goods and the numeraire good  $m$  and is given by

$$U(e, q_{1H}, q_{2H}, m) = a(q_{1H} + q_{2H}) - \frac{1}{2}(q_{1H}^2 + q_{2H}^2 + 2eq_{1H}q_{2H}) + m, \quad (1)$$

where  $e \in [0, 1]$  is an inverse measure of product differentiation and  $q_{1H}$  and  $q_{2H}$  denote consumption of the good produced by firm 1 and 2, respectively. Utility maximisation then gives

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<sup>4</sup>Scherer and Ross (1990) suggest that at about three-fourth of R&D investment by firms in the USA are devoted to product innovation.

rise to the following linear inverse demand functions

$$p_{1H}(e, q_{1H}, q_{2H}) = a - (q_{1H} + eq_{2H}), \quad (2)$$

$$p_{2H}(e, q_{1H}, q_{2H}) = a - (eq_{1H} + q_{2H}), \quad (3)$$

where  $p_{iH}$  is the price of firm  $i$ 's good in Home.

On the supply side, the two firms are assumed to compete as Cournot duopolists in segmented markets. Firms incur symmetric trading costs of  $t$  per unit of exports. Trading costs are exogenously given and reflect a wide range of costs, including, for instance, transportation expenditures, tariffs or costs of border formalities.

In order to produce one unit of its respective good, firm  $i$  has to employ  $\alpha(k_i) \in [0, a]$  units of unskilled labour. Unit costs of production are then given by  $\alpha(k_i)w$  with  $w$  being the (exogenous) wage rate of the unskilled.<sup>5</sup> By increasing the investment in process R&D, denoted by  $k_i$ , firms can lower their unit requirements in unskilled labour. It is assumed that  $\alpha' < 0$ ,  $\alpha'' \geq 0$ . Moreover, the competitors determine the extent of product differentiation,  $e(d_1, d_2)$  with  $\frac{\partial e}{\partial d_i} < 0$  and  $\frac{\partial^2 e}{\partial^2 d_i} \geq 0$ , through investment in product innovation  $d_i$ . Note that product R&D shifts outward not only the demand function of the innovating firm but also the one of its competitor. The costs of R&D investment are incurred in terms of wages for skilled workers. In order to undertake process and product R&D investment, firms have to hire  $S^k(k_i)$  and  $S^d(d_i)$  skilled workers, respectively, with  $S^{k\prime} > 0$ ,  $S^{d\prime} > 0$  and  $S^{k\prime\prime} > 0$ ,  $S^{d\prime\prime} > 0$ . To obtain interior solutions, it is further imposed that  $S^k(0) = 0$ ,  $S^d(0) = 0$ , and  $\lim_{k_i \rightarrow k_i^*} S^k(k_i) = \infty$  (with  $\alpha(k_i^*) = 0$ ),  $\lim_{d_i \rightarrow d_i^*} S^d(d_i) = \infty$  (with  $e(d_1^*, d_2^*) = 0$ ). Skilled workers are paid an exogenous wage rate  $r$ .

The profit of the firm located in Home is then given by

$$\begin{aligned} \Pi_1 = & p_{1H}(e, q_{1H}, q_{2H}) q_{1H} + (p_{1F}(e, q_{1F}, q_{2F}) - t) q_{1F} - (q_{1H} + q_{1F}) \alpha(k_1) w \\ & - (S^k(k_1) + S^d(d_1)) r, \end{aligned} \quad (4)$$

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<sup>5</sup>Section 5 briefly describes how the setting could be implemented into a general equilibrium framework with endogenous factor prices.

where the subscript  $F$  is used to mark variables referring to Foreign. Firms maximise profits by choosing simultaneously output in the two markets as well as their investments in process and product innovation.<sup>6</sup>

### 3 Trade Liberalisation and R&D Investment

The optimal levels of process and product R&D are considered first. Taking the first derivative of profits with respect to the investment in process innovation yields

$$\frac{\partial S^k(k_1)}{\partial k_1} r = -\frac{\partial \alpha(k_1)}{\partial k_1} (q_{1H} + q_{1F}) w. \quad (5)$$

Marginal costs equal the incremental increase in wages paid to skilled workers, while benefits are given in terms of the marginal reduction in production costs. The first order condition for the optimal level of product innovation reads

$$\frac{\partial S^d(d_1)}{\partial d_1} r = -\frac{\partial e(d_1, d_2)}{\partial d_1} (q_{2H} q_{1H} + q_{2F} q_{1F}). \quad (6)$$

Again, marginal costs of investing in process innovation equal the marginal increase in the employment of skilled workers times the wage rate. Marginal benefits are given by the resulting increase in product prices in the two markets multiplied by the respective output level.

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<sup>6</sup>In an alternative set up, investment decisions might be made before production takes places. Then firms also face strategic motives to undertake R&D investment. However, this would not change the results of the paper. The strategic motives for R&D investment are also well understood and discussed in, for instance, Lin and Saggi (2002), Neary (2002) and Rosenkranz (2003).

Holding R&D investments fixed, one can further derive the optimal output decisions as

$$q_{1H} = \begin{cases} \frac{1}{2}(a - \alpha(k_1)w) & \text{for } \frac{2}{4-e^2}(e\alpha(k_2)w - 2\alpha(k_1)w - 2t) \\ & + \frac{2}{2+e}a \leq 0 \\ \frac{1}{4-e^2}[(2-e)a + et - 2\alpha(k_1)w + e\alpha(k_2)w] & \text{otherwise} \end{cases} \quad (7)$$

$$q_{1F} = \begin{cases} 0 & \text{for } \frac{2}{4-e^2}(e\alpha(k_2)w - 2\alpha(k_1)w - 2t) \\ & + \frac{2}{2+e}a \leq 0 \\ \frac{1}{4-e^2}[(2-e)a - 2t - 2\alpha(k_1)w + e\alpha(k_2)w] & \text{otherwise} \end{cases} \quad (8)$$

In the (symmetric) Cournot equilibrium, it further holds that  $q_{1H} = q_{2F}$ ,  $q_{1F} = q_{2H}$  as well as  $d_1 = d_2 = d$ ,  $k_1 = k_2 = k$ . Equations (5) - (8) can now be used to analyse the link between trade liberalisation, i.e. a decrease in trading costs  $t$ , and firm's investment in product and process innovation.

Consider first the case, in which trade barriers will prevent firms from exporting. The competitors act as unconstrained monopolists in their national markets. While the monopolists will invest in process innovation to reap the benefits of reducing costs of their production for the national market, they refrain from investing in product innovation.<sup>7</sup> The reason is simply that a monopolist does not profit from differentiating its product from the one of a non-existing competitor. Marginal decreases in trading barriers will not alter the equilibrium outcome as long as exports are not profitable. Hereafter, attention is restricted to the more interesting case of positive levels of intra-industry trade.<sup>8</sup>

Equations (7) and (8) show that with positive exports trade liberalisation has two competing effects on firm's optimal output level for any given level of R&D investment. On the one hand, protection of the domestic market and, hence, domestic sales decline. On the other hand, reducing trading barriers will increase exports. It is easily verified that due to the increase in competitive pressures in both markets the positive effect on output has to prevail (i.e.  $\partial(q_{1H} + q_{1F})/\partial t < 0$ ). This, in turn, will affect the incentives of firms to undertake R&D in-

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<sup>7</sup>Formally, this can be seen from equation (6) and the fact that  $q_{1F} = q_{2H} = 0$ .

<sup>8</sup>A sufficient but not necessary condition for positive levels of intra-industry trade is  $a - \alpha(0)w > 2t$ .

vestments.

First, a higher level of total output increases the benefits of reducing marginal production costs thereby inducing additional investment in process R&D.<sup>9</sup> Second, the pro-competitive effect of trade liberalisation also provides additional incentives to invest in product innovations. In the domestic market, intensifying foreign competition makes product differentiation more valuable since it now has a stronger impact on market prices. This effect dominates the negative impact of reduced domestic output. In the export market, the ability to charge higher prices (for a given level of output) pays off more with low levels of trading costs because of the rise in production for the foreign market. The effect exceeds the negative one resulting from lower output of the domestic firm (leading to lower benefits in terms of the impact product differentiation has on the market price).

Formally, the positive effect of trade liberalisation on product innovation can be shown by differentiating the marginal benefit of product R&D with respect to  $t$  and combine it with  $q_{1H} = q_{2F}$ ,  $q_{1F} = q_{2H}$  and equations (7) and (8) to find

$$\begin{aligned} \frac{\partial \left( -\frac{\partial e(d_1, d_2)}{\partial d_1} (q_{2H} q_{1H} + q_{2F} q_{1F}) \right)}{\partial t} &= -2 \frac{\partial e(d_1, d_2)}{\partial d_1} \left( \frac{\partial q_{1H}}{\partial t} q_{1F} + \frac{\partial q_{1F}}{\partial t} q_{1H} \right) \\ &= -2 \frac{\partial e(d_1, d_2)}{\partial d_1} \left( \frac{e}{4 - e^2} q_{1F} - \frac{2}{4 - e^2} q_{1H} \right) < 0, \end{aligned} \quad (9)$$

which has to hold given  $\frac{\partial e}{\partial d_1} < 0$ ,  $2 > e$  and  $q_{1H} > q_{1F}$ .

Now consider the subsequent effect of increasing the investment in (process and product) R&D. Not surprisingly, lower marginal production cost will induce firms to raise the output for both markets. With  $k_1 = k_2 = k$  the derivatives of output with respect to the investment in product R&D are given by

$$\frac{\partial q_{1H}}{\partial k} = \frac{\partial q_{1F}}{\partial k} = -\frac{1}{4 - e^2} (2 - e) \frac{\partial \alpha(k)}{\partial k} w > 0. \quad (10)$$

Thus, process innovation will expand output levels. Equations (5) and (6) show that this will lead to further investments in process *and* product R&D (remember that  $q_{1H} = q_{2F}$  and  $q_{1F} = q_{2H}$  in equilibrium). In particular, note that higher equilibrium levels of  $k$  provide additional incentives

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<sup>9</sup>This effect has also been found by Haaland and Kind (2004).

for a firm to invest in product R&D for two reasons. First, the production of the competitor increases and, hence, product differentiation yields higher marginal benefits in terms of the positive effect on market prices. Second, the firm's own output increases and the higher market prices apply to a higher level of production.

A similar result can be established for investment in product R&D. Higher degrees of product differentiation ( $\Delta e < 0$ ) extend market size<sup>10</sup> and increase total production. With  $k_1 = k_2 = k$  one obtains

$$\frac{\partial(q_{1H} + q_{1F})}{\partial e} = -\frac{1}{(2+e)^2}[2a - t - 2\alpha(k)w] < 0. \quad (11)$$

Hence, product innovation leads to higher output levels and provides further incentives for process innovation. The subsequent effect on product R&D depends on the product rather than the sum of the two output levels and is less obvious. While a higher degree of product differentiation unambiguously raises exports, the marginal effect on domestic output is undetermined and depends on the level of trading barriers. Taking the first derivatives of equations (7) and (8) with respect to  $e$  (and imposing  $k_1 = k_2 = k$ ) yields

$$\frac{\partial q_{1H}}{\partial e} = -\frac{a - \alpha(k)w}{(2+e)^2} + \frac{(4+e^2)t}{(4-e^2)^2}, \quad (12)$$

$$\frac{\partial q_{1F}}{\partial e} = -\frac{a - \alpha(k)w}{(2+e)^2} - \frac{4et}{(4-e^2)^2} < 0. \quad (13)$$

Inserting the upper and lower bounds of  $t$  for positive trading volumes (as given by  $(1-1/2e)(a - \alpha(k)w)$  and 0) into equation (12) shows that the derivative might take either sign.<sup>11</sup> For large levels of trading costs, the domestic firm gains little from product differentiation in the domestic market. Export volumes are low and a decreasing  $e$  leads to relatively small gains in terms of higher market prices. On contrary, the exporter can charge considerably higher prices following a reduction in  $e$  and therefore expand exports significantly. Since output levels are strategic substitutes, the domestic firm responds by cutting output levels. For high levels of protection the latter effect might well outweigh the positive effect and domestic output shrinks.

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<sup>10</sup>Note that demand for a given price level is increasing in the degree of product differentiation.

<sup>11</sup>Substituting in the upper limit for  $t$  reveals that the resulting expression is positive for  $2e - 1/2e^3 > 0$ . This condition is fulfilled in the relevant range of  $0 < e < 1$ .

However, it can be shown that even if product innovation led to decreasing levels of domestic output, the positive effect on exports would be large enough to increase the marginal benefits of product R&D even further. A formal proof of this finding is provided in the appendix A.2. The main results of this section are summarised in

**Proposition 1.** *For positive levels of intra-industry trade lower trading barriers (lower values of  $t$ ) will increase total output and the investment of firms in both process and product R&D. Higher investment in process and product innovations will translate into further changes in output, which induce firms to invest even more in both types of R&D. Thus, process and product R&D are found to be complementary.*

## 4 Trade Liberalisation and Relative Labour Demand

After having analysed the effects of trade liberalisation on the choice of output levels and R&D investments, the subsequent impact on relative labour demand is examined now. Demand for skilled workers  $S$  is the sum of workers required for the chosen level of process and product R&D, respectively. Demand for unskilled workers  $U$  is given by total output multiplied by  $\alpha(k_i)$ , the requirement of unskilled workers per unit of production. Relative labour demand of firm 1 can therefore be written as

$$\left(\frac{S}{U}\right)^{\text{Demand}} = \frac{S^k(k_1) + S^d(d_1)}{(q_{1H} + q_{1F})\alpha(k_1)}. \quad (14)$$

Differentiating with respect to  $t$  gives the effects of marginal changes in trading costs on relative skill demand

$$\begin{aligned} \frac{\partial \left(\frac{S}{U}\right)^{\text{Demand}}}{\partial t} &= \frac{\left(\frac{\partial S^k(k_1)}{\partial t} + \frac{\partial S^d(d_1)}{\partial t}\right)(q_{1H} + q_{1F})\alpha(k_1)}{[(q_{1H} + q_{1F})\alpha(k_1)]^2} - \frac{\frac{\partial \alpha(k_1)}{\partial t}(S^k(k_1) + S^d(d_1))(q_{1H} + q_{1F})}{[(q_{1H} + q_{1F})\alpha(k_1)]^2} \\ &\quad - \frac{\frac{\partial(q_{1H} + q_{1F})}{\partial t}(S^k(k_1) + S^d(d_1))\alpha(k_1)}{[(q_{1H} + q_{1F})\alpha(k_1)]^2}. \end{aligned} \quad (15)$$

The analysis of equation (15) leads directly to

**Proposition 2.** *Trade liberalization has three competing effects on relative skill demand. First, lower trading barriers increase the investment in product and process innovation, which translates*

into higher demand for skilled workers. Second, investment in process innovation reduces the per unit requirements of unskilled labour in production. Hence, for any given level of output demand for the unskilled declines. The third effect works in the opposite direction. Trade liberalisation increases output and raises the demand for unskilled workers holding  $\alpha(k_i)$  constant.

Without additional functional form assumptions the sign of equation (15) can not be determined. In order to learn more about the interaction between trade liberalisation, investment in R&D, and relative skill demand, specific functional forms are considered now. Following the relevant literature<sup>12</sup> R&D investment is assumed to reduce production costs and to increase product differentiation in a linear way. The degree of product differentiation is then given by  $e = 1 - (d_1 + d_2)$  with  $d_i \in [0, 1/2]$ , while the requirement of unskilled labour per unit of output is determined as  $\alpha(k_i) = \bar{c} - k_i$  with  $k_i \in [0, \bar{c}]$ . Furthermore, investment costs are assumed to be quadratic, i.e.  $S^k(k_i) = 1/2k_i^2$  and  $S^d(d_i) = 1/2d_i^2$ . With these functional form assumptions, the first-order conditions for the optimal levels of investment in process and product investment for firm 1 read

$$k_1 r = (q_{1H} + q_{1F})w, \quad (16)$$

$$d_1 r = q_{2H} q_{1H} + q_{2F} q_{1F}. \quad (17)$$

Now, one can solve for R&D investments, which then determine skilled labour demand given the functional form assumptions. Substituting into equation (14), imposing  $q_{1H} = q_{2F}$ ,  $q_{1F} = q_{2H}$  and also replacing  $\alpha(k_1)$  by  $\bar{c} - k_1$  yield

$$\left(\frac{S}{U}\right)^{\text{Demand}} = \frac{\frac{w^2}{2r^2}(q_{1H} + q_{1F})^2 + \frac{2}{r^2}(q_{1H}^2 q_{1F}^2)}{(q_{1H} + q_{1F})(\bar{c} - k_1)}. \quad (18)$$

This expression allows to find an unambiguous effect of trade liberalisation on relative skill demand. In fact, differentiating with respect to trading barriers and simple calculus reveal

**Proposition 3.** *With quadratic investment costs and linear effects of R&D investments on*

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<sup>12</sup>See for instance, Neary (2002) Haaland and Kind (2004) for process R&D as well as Lin and Saggi (2002) for process and product R&D.

*production cost and the degree of product differentiation, lower trading costs will raise skill demand. In fact, the first effect identified in proposition 2 (i.e. the direct positive effect on skilled labour demand) suffices to outweigh the third (i.e. the positive effect on the demand for the unskilled via the rise in output levels).*

The proof is relegated to appendix A.3.

## 5 Concluding Remarks

This paper has set up a simple model of international oligopoly to study the interaction between lower trading barriers and the investment of firms in process and product innovation. Increased competition following trade liberalisation induces firms to bring down production costs by investing more aggressively in process R&D. At the same time, competitors expand their investments in product innovation in order to reduce the substitutability of their products. Assuming R&D to be intensive in skilled-labour (relative to production), the paper further illustrates that trade liberalisation may increase the relative demand for skilled workers.

In order to study the effects of the interaction between trade liberalisation and R&D investment on aggregate labour markets more thoroughly, a highly relevant path for further research is the integration of the model into a general equilibrium framework. A promising way to proceed could be the development of a General Oligopolistic Equilibrium Model (GOLE) as proposed by Neary (2003). The key idea of this class of models is to think of firms as being large in their sectors but small in the economy as a whole. Consumers have additively separable preferences defined over a continuum of goods produced in a continuum of industries. Since firms are then small in comparison to the economy they take aggregate variables such as factor prices and aggregate income as given. Hence, the approach avoids the usual problems of modelling oligopolistic competition in general equilibrium.

Applying the concept to the present paper, one might think of a model with two symmetric countries. Each country hosts a continuum of sectors. Abstracting from differences across sectors, industries are identical to the model described in section 2. Trade liberalisation then raises skill demands in all sectors. On the labour market, the relative supply of skilled to unskilled

workers may increase with relative factor prices. Increasing skill demands (following a decline in trading costs) would translate into higher factor prices and also increase the aggregate relative supply of skilled labour. These findings correspond with the empirical observations for the US labour market.

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## A Appendix

### A.1 Figures



Figure 1: Industrial R&D Expenditures, Total and Relative to GDP, USA, 1960-2004 (Source: National Science Foundation, Data for 2004 are Projections)

### A.2 Proof of Proposition 1

*Proof.* What remains to be shown for the proposition to hold is that increasing the investment in product R&D will induce output changes, which further increase the incentives for product innovation. In the symmetric equilibrium, marginal benefits of investing in product innovation are increasing in  $q_{1F}q_{1H}$ . Taking the first derivative with respect to  $e$  gives

$$\frac{\partial(q_{1F}q_{1H})}{\partial e} = q_{1F} \frac{\partial q_{1H}}{\partial e} + q_{1H} \frac{\partial q_{1F}}{\partial e}, \quad (19)$$

which has to be negative for the proposition to hold (remember that  $e$  is an *inverse* measure of product differentiation). Substituting equations (12) and (13) into (19) and rearranging gives the following condition for  $\frac{\partial(q_{1F}q_{1H})}{\partial e} < 0$

$$\frac{(q_{1F} + q_{1H})(a - \alpha(k)w)}{(2 + e)^2} + \frac{4q_{1H}et}{(4 - e^2)^2} \geq \frac{q_{1F}(4 + e^2)t}{(4 - e^2)^2}. \quad (20)$$

Since  $q_{1H} \geq q_{1F}$  for  $t \geq 0$ , the condition above will still hold if one replaces  $q_{1H}$  by  $q_{1F}$  on the left hand side. Simple calculation then reveals that the condition reduces to

$$2(a - \alpha(k)w) \geq t. \quad (21)$$

which has to hold for positive levels of intra-industry trade.  $\square$

### A.3 Proof of Proposition 3

*Proof.* Differentiating equation (18) with respect to  $t$  (and ignoring the common denominator) shows that the first effect identified in proposition 2 will outweigh the third if the following condition holds

$$\begin{aligned} & \frac{w^2}{r^2}(q_{1H} + q_{1F}) \left( \frac{\partial q_{1H}}{\partial t} + \frac{\partial q_{1F}}{\partial t} \right) (q_{1H} + q_{1F})(\bar{c} - k_1) + \\ & \frac{4}{r^2} \left( q_{1H}q_{1F}^2 \frac{\partial q_{1H}}{\partial t} + q_{1H}^2q_{1F} \frac{\partial q_{1F}}{\partial t} \right) (q_{1H} + q_{1F})(\bar{c} - k_1) - \\ & \left( \frac{w^2}{2r^2}(q_{1H} + q_{1F})^2 + \frac{2}{r^2}(q_{1H}^2q_{1F}^2) \right) \left( \frac{\partial q_{1H}}{\partial t} + \frac{\partial q_{1F}}{\partial t} \right) (\bar{c} - k_1) \leq 0. \end{aligned} \quad (22)$$

Multiply out and rearrange to obtain

$$(\varphi + 4q_{1H}q_{1F}^3) \frac{\partial q_{1H}}{\partial t} + (\varphi + 4q_{1H}^3q_{1F}) \frac{\partial q_{1F}}{\partial t} \leq 0, \quad (23)$$

with  $\varphi = 1/2w^2q_{1H}^2 + w^2q_{1H}q_{1F} + 1/2w^2q_{1F}^2 + 2q_{1H}^2q_{1F}^2 > 0$ . For positive levels of exports the condition has to be fulfilled since  $-\frac{\partial q_{1F}}{\partial t} > \frac{\partial q_{1H}}{\partial t}$  and  $q_{1H} \geq q_{1F} > 0$ . This proves the second part of proposition 3. The first part follows directly from the fact that the remaining second effect

will also depress the demand for unskilled workers, i.e. work into the same direction as the first one does. □

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