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ABSTRACT

Defensive Innovations[*]

Defensive innovations in developed countries can explain the empirical phenomenon that openness towards trade with less-developed countries does not necessarily induce a substantial increase in the wage differential and trade volumes. Building on step-by-step innovations as introduced by Aghion et al. (2001), we show that defensive innovations can result from private incentives. In particular, minimum wages can induce defensive innovations which then redistribute income away from workers. Suggestive empirical evidence is consistent with the implications of defensive innovations for wage differentials, trade volumes and the sectorial composition within and across OECD countries.

JEL Classification: F1, F4, O3

Keywords: Step-by-step innovations, openness, minimum wage

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1 Introduction

There has been a substantial debate on the effects of trade between developed and less-developed countries on labor markets (see, e.g., Johnson and Stafford (1999) and their references). In this debate it has been noted that openness or potential trade between developed and less-developed countries might induce defensive innovations in the developed countries, i.e., innovations which induce more R&D in the sector *adversely* affected by openness and offset part of the initial comparative advantage (see, e.g., Wood (1994)).

However, microfounded models analyzing the effects of trade on technology change such as Acemoglu (1999) and Acemoglu and Zilibotti (2000) have cast doubt on this hypothesis. In these models trade induces skill-biased technological progress because openness lets the relative price of the skill-intensive good increase in the developed country. This price effect increases the wage differential between skilled and unskilled workers not only statically, but also dynamically. Acemoglu (1999) shows that with property right enforcement there is an additional market-size effect of openness resulting from the relatively higher world endowment in unskilled labor accessible to developed countries. This potentially outweighs the price effect so that unskilled-complementary technological change can occur which decreases the wage differential. Technology change is directed to the factor that is relatively more abundant and cheaper. In our model we point out that openness might induce more R&D in the *sector* adversely affected by trade which is what we call defensive innovations. Note that neither the price nor the market-size effect can generate defensive innovations in general.[1]

In this paper we show that defensive innovations can result from private incentives.[2] Introducing the idea of step-by-step innovation (see Aghion et al. (2001) and their references) into a

[1]In our model unskilled labor is only used in one sector. This is a special case in which also the market-size effect can induce defensive innovations. However, in our modeling structure defensive innovations are possible as well if skilled and unskilled labor are used in both sectors.

[2]Besides private incentives it can be optimal for the government to subsidize defensive innovations, if rigid labor markets imply substantial unemployment in the sector adversely affected by openness (see Koeniger (2001)).

standard trade model, we show, in particular, how defensive innovations depend on labor market institutions. Openness can induce defensive innovations either if competition or imitation increases for intermediate goods used together with unskilled labor in the final production stage; or if there exist minimum wages.

Besides the theoretical interest defensive innovations have the potential to explain differences in wage differentials, trade volumes and the sectorial composition within and across OECD countries with different labor market institutions. As a reference we summarize the empirical evidence which we can explain with the model laid out below.

Wage Differentials OECD countries have become substantially more open in the last 50 years as average ad-valorem tariffs fell from 40% to 4% in eight rounds of GATT negotiations. However, empirical studies have difficulties to find substantial effects of openness on wage differentials across decades which would be suggested by standard trade models (see Johnson and Stafford (1999) for a recent survey). Across countries wage differentials are more compressed in continental European countries than in the US and the UK where wage floors induced by unions or minimum wages are less important. Since the mid-70s wage differentials have remained relatively stable in continental Europe whereas they have increased in the US and the UK. Although wage rigidities are more important in continental European countries, empirical evidence shows that unskilled unemployment has *not* become relatively more important in these countries compared to countries with more flexible labor markets (see Nickell and Bell (1996)). Skill-biased technology change or openness alone cannot explain this empirical evidence.

Trade Volumes Notwithstanding the substantial increase in openness, the absolute size of trade volumes between OECD and non-OECD countries has remained small –less than 3% of manufacturing GDP for the G7 countries[3]; and transport costs seem to be too small to explain the "mystery of missing trade" (see Anderson (2000)). Moreover, these trade volumes seem to be smaller in

[3]The figure is obtained from the OECD Statistical Compendium.

continental European countries with more wage rigidities than in the US (see Sapir (2000)).

Sectorial Composition At the end of the paper we provide suggestive evidence that unskilled-labor intensive sectors are relatively larger in OECD countries with higher wage floors.

We put forward defensive innovations as a mechanism which can rationalize these empirical observations. These innovations will make unskilled workers more productive ceteris paribus. Of course, this does not imply that we consider other types of technology change as not important. As a matter of fact we will show that relative price changes resulting from openness induce skill-biased technology change. However, the incentives for innovations are changed by, e.g., labor market institutions so that equilibrium outcomes for trade volumes, wage differentials and the sectorial composition differ in countries with different labor market institutions whereas this is not necessarily the case for unemployment.

Besides the papers already mentioned above the following papers are closely related to our research. Thoenig and Verdier (2000) analyze the effects of differences in property right enforcement on technological change in a model of trade between developed and less-developed countries. Better enforcement in developed countries induces skill-biased technological change. The technology change occurs to prevent spill-overs. It is skill-biased in the developed countries because the less-developed countries use less skill-intensive technologies. On the transition path the wage differential can increase whereas trade between countries is quite stable for certain parameter values.

The idea of factor-price-induced technology change has been mentioned already by Hicks (1935) (see also the survey of Thirtle and Ruttan (1987)). In particular, two recent papers by Bester and Petrakis (2001) and Hellwig and Irmen (2001) are related to our analysis of the effects of minimum wages on technology change. In their closed-economy models higher exogenous wage growth can induce technology change which makes workers more productive. In steady state wages and productivity grow at the same rate. We analyze the effect of the *level* of minimum wages on innovation where innovations redistribute income from workers to firms. Innovations which are unexpected for wage setting institutions would have similar effects, if we allowed the minimum wage to change over time. The redistribution of rents through productivity increases is in the spirit of Acemoglu and Pischke (1999). They show in a model with labor market frictions that a wage structure which is distorted in favor of unskilled workers can make firms invest in general training in order to obtain a higher share of the rents.

The rest of the paper is structured as follows. We present the model in Section 2. In Section 3 we point out scenarios under which openness induces defensive innovations, illustrate these scenarios numerically and emphasize the empirical implications. In Section 4 we provide evidence on the empirical implications of defensive innovations for the sectorial composition. Section 5 concludes.

2 The Model

The model has a final and intermediate-good sector. In the intermediate sector firms perform R&D.

Final goods The final-good sector is modelled similar to a standard Heckscher-Ohlin-Samuelson model. The economy produces two final goods which both need an intermediate input and are imperfect substitutes. Consumer demand for these goods is assumed to be homothetic.[4] To keep the model as simple as possible we assume that sector one produces a final good using unskilled labor L and the sector-specific intermediate good x_1. Sector two produces another final good using skilled labor H and the intermediate good x_2. The production functions $F_i(.)$ of both sectors are assumed to have constant returns to scale and to be strictly concave. We assume free entry, perfect competition and no factor-intensity reversal.

Since we focus on the effects of trade between developed and less-developed countries, we are only interested in inter-industry and not in intra-industry trade. For trade occurring just because of differences in factor endowment and not because of a scale effect, we need a production technology in the final goods' sector that does not feature fixed costs. Given the assumption of free entry perfect competition is the natural market structure.

[4] We do not characterize the demand side further because it only matters for the determination of the trade volumes in the open economy.

Firms in sector one solve the maximization problem

$$\max_{\{L(t),x_1(t)\}} J_1 = \int_0^\infty e^{-\overline{r}t} \left[P_1(t)F_1(L(t),x_1(t)) - W_l(t)L(t) - R_1(t)x_1(t)\right] dt$$

and firms in sector two do solve

$$\max_{\{H(t),x_2(t)\}} J_2 = \int_0^\infty e^{-\overline{r}t} \left[P_2(t)F_2(H(t),x_2(t)) - W_h(t)H(t) - R_2(t)x_2(t)\right] dt \ ,$$

where $\overline{r}$ is the market interest rate, W_l is the wage of the unskilled, W_h is the wage of the skilled, R_1 is the marginal product of intermediate good x_1, R_2 is the marginal product of intermediate good x_2, and P_i is the price of final good i. For concreteness we parametrize the production functions as $F_1(L,x_1) = L^{\frac{1}{2}} + (x_1)^{\frac{1}{2}}$ and $F_2(H,x_2) = H^{\frac{1}{2}} + (x_2)^{\frac{1}{2}}$.Writing both production functions in intensive form, $f_1(l) = l^{\frac{1}{2}}$ and $f_1(h) = h^{\frac{1}{2}}$, where $l \equiv \frac{L}{x_1}$, $h \equiv \frac{H}{x_2}$, we get the standard static first order conditions omitting time indices for convenience:

$$W_l = \frac{P_1}{2\sqrt{l}}, \tag{1}$$

$$W_h = \frac{P_2}{2\sqrt{h}} \ , \tag{2}$$

$$R_1 = \frac{P_1}{2}\sqrt{l} \ , \tag{3}$$

and

$$R_2 = \frac{P_2}{2}\sqrt{h} \ . \tag{4}$$

We assume a small open economy. The final goods are freely traded within a large set of countries so that the relative price of the final good is given. An increase in openness is understood as more openness towards trade with less-developed countries, i.e., an enlargement of the set of countries a developed country trades with. Because of the small open economy assumption, the price $P \equiv \frac{P_2}{P_1}$ is exogenous. As we will see below R_i, $i = 1, 2$, will be determined in the intermediate-good sector. Hence, the four equations (1)~(4) fully determine the remaining four unknowns $W_l(R_1)$, $W_h(R_2)$, $l(R_1)$ and $h(R_2)$. Demand only matters for trade volumes.

Intermediate goods Two different intermediate goods are produced by two sectors. To be consistent with the structure of the model above we assume that the first intermediate good x_1 is used for the production of the first final good. Analogously, the second intermediate good x_2 is used for the production of the second final good. Instead of perfect competition the intermediate-good markets are both assumed to be a duopoly.[5] This asymmetric assumption –compared with the final goods' sector– is made in order to analyze innovations or R&D. These are naturally associated with rents and thus a market structure other than perfect competition needs to be introduced into the model. For an analysis of an increase in product market competition at least two firms are necessary. Hence, choosing the simplest possible structure, the market for intermediate goods is modelled as a duopoly. For simplicity we do not allow free entry in the market for intermediate goods so that rents occur in this market although the production function has constant returns in capital (see below). This is done to avoid that unit costs depend on the quantities produced. With fixed costs the most cost-efficient way to produce the intermediate good would be achieved with one firm only. An increase of competition in the classic Schumpeterian monopoly model results in the standard negative effects on research efforts. Such a framework would not let defensive innovations arise.

Industry output for the two intermediate goods is characterized by

$$x_i = \phi_i(x_{ai}, x_{bi}) = (x_{ai}^{\alpha_i} + x_{bi}^{\alpha_i})^{\frac{1}{\alpha_i}},$$

[5] The intermediate good's market and R&D activity is modelled very similarly to Aghion et al. (2001). Hence, we refer to their paper for the discussion of the major assumptions and more detailed derivations and only point out the crucial differences in our presentation.

where $\alpha_i \in (0;1)$, $i = 1, 2$, and x_{ai} and x_{bi} is the output of the intermediate good of the two firms a and b in sector i. The demand for the intermediate goods is determined by equations (1)~(4). Resulting from the parametrization of the production functions in the final-good sector, in each final-good sector an amount $M_i \equiv \frac{P_i}{2} R_i^{-1}$ is spent on the intermediate good. Maximizing $\phi_i(.)$ subject to $p_{ai}x_{ai} + p_{bi}x_{bi} = M_i$ results in the following factor demand of the final-good sector for the intermediate good x_i of firm a and b, respectively:

$$x_{ai} = \frac{p_{ai}^{\frac{1}{\alpha_i - 1}}}{p_{ai}^{\frac{\alpha_i}{\alpha_i - 1}} + p_{bi}^{\frac{\alpha_i}{\alpha_i - 1}}} M_i$$

and

$$x_{bi} = \frac{p_{bi}^{\frac{1}{\alpha_i - 1}}}{p_{ai}^{\frac{\alpha_i}{\alpha_i - 1}} + p_{bi}^{\frac{\alpha_i}{\alpha_i - 1}}} M_i,$$

$i = 1, 2$, where p_{ai} denotes the price of the intermediate good produced by firm a in sector i.

Assume that firms in the intermediate-good sector compete in prices[6] so that the elasticity of demand (defined as a positive number) for the demand functions derived above is

$$\eta_{ji} = \frac{1 - \alpha_i \lambda_{ji}}{1 - \alpha_i} , \tag{5}$$

for each firm $j = a, b$ where $i = 1, 2$ for each sector. The revenue, $\lambda \equiv px$, can be written as

$$\lambda_{ji} = \frac{p_{ji}^{\frac{\alpha_i}{\alpha_i - 1}}}{p_{ai}^{\frac{\alpha_i}{\alpha_i - 1}} + p_{bi}^{\frac{\alpha_i}{\alpha_i - 1}}} M_i , \tag{6}$$

where $\lambda_a + \lambda_b = M_i$.

Let us now assume that each unit of the intermediate good is produced with capital. This assumption simplifies the analysis considerably. If the same factors were employed for producing the intermediate and the final good, factor price changes in the final-good sector would feed back into the intermediate-good sector and vice versa. We close down this mechanism for clarity.

The production function is assumed to have constant returns. Capital is fully elastically supplied and its return, $\bar{r}$, is given which is consistent with the small-open economy assumption and perfect

[6] For firms competing in quantities and a comparison of Bertrand and Cournot equilibria see Aghion et al. (1997).

capital mobility. The cost of every production unit is ρ_{ji} which varies according to how many units of capital are necessary to produce the intermediate good. Given these assumptions, in equilibrium the revenue-maximizing price of firm j in the intermediate-good sector i is

$$p_{ji} = \frac{\eta_{ji}}{\eta_{ji} - 1}\rho_{ji} = \frac{1 - \alpha_i \lambda_{ji}}{\alpha_i \left(1 - \lambda_{ji}\right)}\rho_{ji} \ . \tag{7}$$

It follows that total profits in equilibrium are

$$\pi_{ji} = \frac{\lambda_{ji}}{\eta_{ji}} = \frac{\lambda_{ji}(1 - \alpha_i)}{1 - \alpha_i \lambda_{ji}} \ . \tag{8}$$

Equations (6)~(8) can be used to solve for unique equilibrium prices, revenues and profits in the two intermediate-good sectors. As is shown in Aghion et al. (2001), for given α_i equilibrium profits of firm j in intermediate-good sector i are determined by the relative cost $z_i \equiv \frac{\rho_{ji}}{\rho_{-ji}}$, $j = a, b$, since the demand for the intermediate good is unit-elastic. The absolute cost level does not matter for profits. Note that in equilibrium $p_i = R_i$, i.e., the intermediate goods are used in the final-good sector so that their price is worth their marginal product.

R&D We use the model of step-by-step innovations of Aghion et al. (2001). In this model competition can have a positive effect on innovations and thus growth which is always negative in the standard Schumpeterian model. Step-by-step innovations mean that a technology laggard first has to catch up before he can become a technology leader in the next step. The crucial feature of this model is that introducing some competition makes profits positively depend on the relative position on the technology frontier which increases the incentive to innovate. Intuitively, there is an incentive to escape competition by innovating.

Each intermediate-good sector is assumed to be a duopoly also in R&D. The R&D effort is assumed to depend only on the firm's current state of technology which implies that we search for symmetric stationary equilibria in Markov strategies. We do derive results for the case of very large innovations since the model simplifies and it is easier to get an intuition. The results are more general, however, as shown by Aghion et al. (2001) because smaller innovations increase the incentive to innovate relatively more resulting from more competitive product markets. With small innovations the appropriability effect of standard Schumpeterian models vanishes. Because of the appropriability effect, competition is bad for growth in standard Schumpeterian models since competition decreases the rents derived from innovation.

In the case of very large innovations there are three states of the firm in the intermediate-good sector $\{1, 0, -1\}$ which denote the technology leader being one step ahead, neck-and-neck firms and the technology laggard, respectively. Step-by-step innovations mean that a technology laggard first has to catch up before he can become a technology leader. Employing $\frac{\beta q_k^2}{2}$, $k \in \{1, 0, -1\}$, units of capital, $\beta > 0$, the firm moves one step forward with the endogenous Poisson hazard rate q_k. Capital is assumed perfectly mobile and needs to be paid the world interest rate $\overline{r}$.[7] Because of very large innovations the technology leader does not exert any research effort, i.e., $q_1 = 0$. The technological follower catches up with the leader at rate $q_{-1} + \xi$ where ξ is the rate of imitation. If this happens, firms are neck-and-neck. Neck-and-neck competition is defined as $z = 1$ where $z_i \equiv \frac{\rho_{ji}}{\rho_{-ji}}$, $j = a, b$. I.e., both firms have the same input requirement for producing one unit of the intermediate good and thus also the same cost. Firms in neck-and-neck competition exert research effort q_0 which is then also the Poisson hazard rate of each firm to become a technology leader. If a firm advances one step, its input requirement for the production of the intermediate good falls by the factor γ^{-1}, $\gamma > 1$. Hence, the relative cost of the technological leader being one step ahead is $z = \gamma^{-1}$.

Using subscripts i, k to denote the relative technology level k in sector i, the expected present value of profits V in the three states satisfies the following equations for small time intervals:

$$\overline{r} V_{i,1} = \pi_{i,1} + (q_{i,-1} + \xi)(V_{i,0} - V_{i,1}) \ , \tag{9}$$

$$\overline{r} V_{i,0} = \pi_{i,0} + q_{i,0}(V_{i,1} - V_{i,0}) + \overset{rival's R\&D}{\overset{\downarrow}{q_{i,0}}} (V_{i,-1} - V_{i,0}) - \frac{\beta \overline{r} (q_{i,0})^2}{2} \tag{10}$$

[7] If R&D were produced with skilled labor, openness would have a direct negative effect on R&D for both intermediate goods if the relative wage of the skilled rises. Letting R&D be produced by a factor with a fixed remuneration simplifies the analysis by closing down this interaction.

and

$$\overline{r}V_{i,-1} = \pi_{i,-1} + (q_{i,-1} + \xi)(V_{i,0} - V_{i,-1}) - \frac{\beta\overline{r}(q_{i,-1})^2}{2} \ . \tag{11}$$

The rate of return from performing R&D has to equal the rate of return available in the market, $\overline{r}$. E.g., in equation (11) for technology laggards, the returns of performing R&D contain profit flows $\pi_{i,-1}$ and the change of the firm's value of moving one step ahead on the technology frontier, $V_{i,0} - V_{i,-1}$, which happens at probability $q_{i,-1} + \xi$. Moreover, there is a flow cost for the R&D effort of $\frac{\beta\overline{r}(q_{i,-1})^2}{2}$.

The resulting optimal research efforts are found maximizing the respective right-hand side of equations (9)~(11):

$$q_{i,1} = 0 \ , \tag{12}$$

$$q_{i,0} = \frac{V_{i,1} - V_{i,0}}{\beta\overline{r}} \tag{13}$$

and

$$q_{i,-1} = \frac{V_{i,0} - V_{i,-1}}{\beta\overline{r}} \ . \tag{14}$$

Equations (9)~(14) can be solved for $q_{i,1}, q_{i,0}, q_{i,-1}, V_{i,1}, V_{i,0}$ and $V_{i,-1}$.

Subtracting equation (10) from equation (9), and equation (11) from equation (10), using equations (13) and (14) yields

$$\frac{1}{2}q_{i,0}^2 + (\overline{r} + \xi)q_{i,0} = \frac{\pi_{i,1} - \pi_{i,0}}{\beta\overline{r}} \tag{15}$$

and

$$\frac{1}{2}q_{i,-1}^2 + (\overline{r} + \xi)q_{i,-1} = \frac{\pi_{i,0} - \pi_{i,-1}}{\beta\overline{r}} + \frac{1}{2}q_{i,0}^2 - q_{i,0}q_{i,-1} \ . \tag{16}$$

Hence,

$$q_{i,0} = -(\bar{r} + \xi) + \sqrt{(\bar{r} + \xi)^2 + \frac{2(\pi_{i,1} - \pi_{i,0})}{\beta \bar{r}}} \tag{17}$$

and

$$q_{i,-1} = -(\xi + \bar{r} + q_{i,0}) + \sqrt{(\xi + \bar{r})^2 + 2(\xi + \bar{r})q_{i,0} + 2q_{i,0}^2 + \frac{2(\pi_{i,0} - \pi_{i,-1})}{\beta \bar{r}}} \ . \tag{18}$$

From Aghion et al. (2001), Proposition 1, we know that $\pi_{i,1} > \pi_{i,0} > \pi_{i,-1}$ and $\pi_{i,1} - \pi_{i,0} > \pi_{i,0} - \pi_{i,-1}$, where the latter implies that $q_{i,0} > q_{i,-1}$, i.e., research effort it largest, if firms are neck-and-neck.

Growth and the wage differential The model's structure implies a steady-state distribution across technology states as is shown by Aghion et al. (2001).[8] Moreover, they derive that the growth rate for the case of very large innovations is

$$g_i = \frac{2q_{i,0}(q_{i,-1} + \xi)}{2q_{i,0} + q_{i,-1} + \xi} \ln \gamma \ . \tag{19}$$

It follows that $\frac{\partial g_i}{\partial q_{-1}} > 0$ and $\frac{\partial g_i}{\partial q_0} > 0$. I.e., the growth rate unambiguously increases in research effort of either laggards or neck-and-neck firms. For the case of small innovations the growth rate increases even more. This is because for large innovations a higher research effort of neck-and-neck firms q_0 increases the probability that one these firms becomes a leader. A leader, however, does not exert any research effort as mentioned above.

For our parametric specification of the final-good production functions, $f_1(l) = l^{\frac{1}{2}}$ and $f_2(h) = h^{\frac{1}{2}}$ in intensive form, both sectors grow at rate $g_i/2$, $i = 1, 2$.

Using equations (1)~(4), substituting out l and h and defining[9] $w_l \equiv \frac{w_l}{P_1}$, $w_h \equiv \frac{w_h}{P_1}$, $r_2 \equiv \frac{R_2}{P_1}$, $r_1 \equiv \frac{R_1}{P_1}$, $P \equiv \frac{P_2}{P_1}$ we find that the wage differential can be written as

$$\ln\left(\frac{w_h}{w_l}\right) = \ln\left(\frac{r_1}{r_2}\right) + 2\ln P. \tag{20}$$

[8]Their results apply to our model once we adapt their argument which holds for a large number of cross-sectional observations to a large number of time-series observations. This is because we only have two sectors in our model.

[9]The choice of the numeraire is irrelevant for the results.

Note that in the unconstrained equilibrium the price of the intermediate good equals its marginal product, i.e., $R_i = p_i$. Equation (20) shows that the wage differential depends on the relative final-good price one the one hand and on the relative price of the intermediate goods on the other hand. The larger P, the relative price of the final good using skilled labor, the larger will be the wage differential. More interestingly, the higher the price of the intermediate good used with unskilled labor the higher is the wage differential: a higher price of the intermediate good induces substitution towards labor in the final-good sector. If $r_1 > r_2$, the intensity of labor is larger in the final-good sector using unskilled labor. This results in a relatively smaller marginal productivity and wage of the unskilled so that the wage differential increases.

From equation (7) we know that $\frac{\dot{p}_i}{p_i} = g_i^{-1}$, where dots denote time derivatives. The complete pass-through of innovations into price changes results from the unit elasticity of the factor demand function. Hence, revenues and profits do not depend on the level of the marginal cost.

Since $\lim_{t\to\infty} R_i = 0$, equations (3) and (4) imply for our parametric specification that $\lim_{t\to\infty} h = \lim_{t\to\infty} l = 0$. For wages it then holds that $\lim_{t\to\infty} w_l = \infty$ and $\lim_{t\to\infty} w_h = \infty$. Using L'Hôpital's rule we find that the wage differential converges to

$$\lim_{t\to\infty} \ln(\frac{w_h}{w_l}) = (g_1)^{-1} - (g_2)^{-1} \quad . \tag{21}$$

In the limit the wage differential depends on relative growth rates of the intermediate-good sectors. The wage of labor used in the faster-growing sector will be relatively higher.

Trade volumes Trade in final goods is determined by the demand side. Assuming a homothetic utility function we can denote demand for final good i as $\theta_i Y$ where $0 \leq \theta_i \leq 1$ and $Y \equiv P_1 F_1 + P_2 F_2$ is aggregate output. Let $\omega_i \equiv \frac{P_i F_i}{Y}$ denote the sector share of sector i. The trade volume for good i per unit of aggregate output can then be defined as

$$T_i = \omega_i - \theta_i \ , \tag{22}$$

where $T_i > 0$ if the good is exported and $T_i < 0$ if the good is imported. Note that there is always balanced trade, $T_1 = -T_2$, because $\omega_1 + \omega_2 = 1$ and $\theta_1 + \theta_2 = 1$.

3 The Effects of Openness

We are now interested to analyze the effects of openness towards trade with less-developed countries on innovations, factor prices and trade volumes in the developed country. We say that defensive innovations occur if openness induces more R&D in the sector adversely affected. We assume that developed countries have a comparative advantage in the production of the skill-intensive good because they are assumed to be relatively abundant in skilled labor compared with the less-developed countries. For simplicity we assume that no trade occurs before developed countries open up to trade with less-developed countries. This facilitates comparisons in the subsequent analysis. We analyze three scenarios:

1. As is standard in the literature, openness towards trade with less-developed countries is modelled as a fall in the relative price of the final good produced with unskilled labor.

2. Openness towards trade with less-developed countries might also imply more competition in the production of the intermediate good in our model. We analyze two cases:

a) competition increases symmetrically for the production of both intermediate goods.

b) competition increases only for the production of the intermediate good used together with unskilled labor in the final-good industry.

3. We analyze interactions between openness and labor market institutions, i.e., minimum wages.

We then provide numerical comparative statics to illustrate the results.

3.1 Openness I: Price Change of Final Goods

The static effects of a decrease of the relative price of the final-good using unskilled labor are standard by construction. Production of the good using skilled labor increases whereas production of the good using unskilled labor falls. It follows from equation (22) that the final good produced with skilled labor will be exported whereas the good produced with unskilled labor will be imported. Moreover, equation (20) implies that the change of final-good prices increases the wage differential.

This effect is mitigated because the price of the intermediate good used together with unskilled labor decreases in relative terms because the demand for the first intermediate good M_1 falls whereas M_2 increases and equations (6) and (7) imply that $\frac{\partial p}{\partial \lambda}\frac{\partial \lambda}{\partial M} > 0$. The intuition is that the fall in M_1 increases the elasticity of demand η (see equation (5)). However, this effect is second-order and can be neglected for marginal changes applying the envelope theorem.

The interesting issue is how the price change affects R&D efforts for the respective intermediate goods.

Remark 1 *A fall in the relative price of the final good produced with unskilled labor increases R&D efforts for the production of the intermediate good used together with skilled labor relative to R&D efforts for the production of the intermediate good used together with unskilled labor.*

Proof: see Appendix.

This is the price effect of openness on R&D which has already been noted by, e.g., Acemoglu (1999). Neither this effect nor the market-size effect mentioned in the Introduction can generate defensive innovations. Instead, the price effect induces skill-biased technology change, i.e., innovations which are complementary to skilled labor.

Note that Remark 1 implies that the static effect of openness on trade volumes and wage differentials is amplified dynamically because equation (19) implies that the skill-intensive sector will grow faster. It follows from equations (21) and (22) that exports of the final good using skilled labor will increase as its share of the economy's output does; and that the wage differential increases further. We now turn to the second scenario where openness increases competition in the intermediate-good sector.

3.2 Openness II: Increase of Competition in Intermediate Goods

If we interpret the two firms in each intermediate-good sector as a foreign and a domestic firm, then more openness, i.e., lower trade barriers, is likely to increase the substitutability between the two goods. Hence, another plausible scenario of openness is that competition increases which we model as an increase in α_i, $i = 1, 2$. Although α_i is really a taste parameter, it relates to standard measures of competition. E.g., a higher α_i implies a higher elasticity of demand and less market power. We first set $\alpha_i = \alpha$ and analyze a symmetric increase of competition in both intermediate-good sectors. We focus on the case of introducing some competition where initially there is no competition at all, i.e., $\alpha_i = 0$. In this case some competition always increases the innovation efforts and thus growth. The results are more general, however, as shown by the numerical simulations of Aghion et al. (2001).

Remark 2 *If $\alpha_i = 0$, a small increase of α*

a) does increase R&D in both intermediate-good sectors.

b) increases production of both final goods, but leaves the trade volume of final goods per output unchanged.

c) increases wages both for the skilled and unskilled, but leaves the wage differential unchanged.

Proof: see Appendix.

A symmetric increase in α lets the price of the two intermediate goods fall by the same amount. Hence, given that we assumed the same parameters of the production functions in the two final-good sectors, the same factor substitution takes place which leaves the wage differential unchanged. Moreover, output growth in both final-good sectors increases by the same amount. Because demand is homothetic, trade volumes per output remain unchanged.

In order to generate defensive innovations we need to go beyond a symmetric increase in competition in both intermediate-good sectors. We will first assume that competition only increases for the intermediate good which is combined with unskilled labor in the final production stage. I.e., α_1 increases whereas α_2 remains unchanged. Since α is a deep parameter we cannot endogenously derive this asymmetric assumption. However, this scenario seems realistic since less-developed countries are probably much more competitive in intermediate goods used in the final-good sector using unskilled labor.[10]

[10] An increase of the probability mass of neck-and-neck firms in this sector would have similar short-run effects. Since research effort is highest if firms are neck-and-neck, this would induce *transitorily* higher growth rates in the

Alternatively, labor market institutions such as minimum wages affect the two final-good sectors asymmetrically as long as unskilled labor is used with different intensities in the two final-good sectors. We will analyze this scenario below.

Remark 3 *If $\alpha_i = 0$, a small increase in α_1*

a) increases R&D for intermediate good 1.

b) decreases the wage differential.

c) induces exports of the final good using unskilled labor and imports of the good using skilled labor.

Proof: a) follows from the proof of the previous proposition. b) and c) follow from the fact that the first intermediate-good sector grows at a faster rate so that the price of the intermediate-good 1 falls at a faster rate. Equations (20) and (22) then imply b) and c).■

Realistically, openness will both decrease the relative price of the final good which is more intensive in unskilled labor and increase competition for the intermediate good.

Remark 4 *If openness implies a decrease in the relative price of the good using unskilled labor and an increase in competition for the production of the intermediate good used in this sector, defensive innovations can occur.*

Since the price effect and the competition effect work in opposite directions, defensive innovations occur when the latter effect is stronger. As long as the competition effect is of some importance, it can explain why the effects of openness towards less-developed countries on wage differentials and trade volumes have been much smaller than expected in the developed countries (see the discussion of the empirical evidence in the Introduction).

An alternative scenario with similar results would be to assume that openness increases the rate of imitation ξ for the intermediate good used with unskilled labor. More imitation increases

unskilled-labor intensive sector, ceteris paribus. It would not affect the steady state, however, because in the long run the fraction of firms competing neck-and-neck does not change.

the probability that technology laggards catch up and hence on the one hand increases growth as neck-and-neck competition becomes more likely. On the other hand more imitation decreases the rents derived from innovation so that the overall effect is not always positive. Aghion et al. (2001) show, however, that some imitation is always good for growth. It is probably realistic that less-developed countries are relatively better at imitating intermediate goods used together with unskilled labor. E.g., Thoenig and Verdier (2000) link the imitation rate to factor endowments. Since unskilled labor is relatively more abundant in less-developed countries, imitation increases if goods are more unskilled-labor intensive. Next, we will show that defensive innovations can also be induced by labor market institutions such as minimum wages.

3.3 Openness III: Minimum Wages

Wages are substantially higher in developed than less-developed countries (see OECD (1998)). It is likely that minimum wages are binding in all OECD countries in comparison with the wage at which unskilled workers in less-developed countries are willing to perform the same task. Thus, openness is likely to make the minimum wage more binding. We now investigate how binding minimum wages affect the interaction between openness and innovations.

Remark 5 *Binding minimum wages increase the possibility of defensive innovations.*

Proof: see Appendix.

The intuition of this result is that a binding minimum wage makes technologically more advanced firms relatively better off. This is because the minimum wage implies a maximum price for the intermediate good. Since the price charged for the intermediate good falls as firms advance on the technology frontier, the constraint is less binding the more technologically advanced is the firm. With minimum wages profits do depend on technology levels and not only on the relative position on the technology frontier.

Remark 5 shows that in countries with minimum wages relatively more defensive technology change might be induced resulting from private incentives. Note that as long as innovations happen, minimum wages are no longer binding in finite time since the productivity of workers increases. Moreover, the result of Remark 5 does not depend on the assumption that unskilled workers are only used in the production of the first final good. All that is needed is that unskilled workers are relatively more important in one of the sectors.

An important caveat of Remark 5 is that the minimum wage cannot be "too binding". If profits in the intermediate-good sector one fall below zero, this sector will close down and consequently also the final-good sector. This seems realistic, given the anecdotal evidence for plant closures in the very unskilled-labor intensive textile industry in developed countries compared with the less unskilled-labor intensive automobile industry in which capital intensity increased dramatically in the last decades.

Remark 5 implies that higher minimum wages do not result in higher unemployment of unskilled workers unless firms close down. This is consistent with empirical evidence of Nickell and Bell (1996) which casts doubt on openness or pure skill-biased technology change being the main explanation for unemployment in OECD countries. Moreover, Remark 5 and Remark 3 imply that defensive innovations have the potential to explain why wage differentials are relatively more compressed and trade volumes are relatively smaller in OECD countries with higher wage floors. The results are in the spirit of the empirical cross-country evidence surveyed by Blau and Kahn (1999). There is strong evidence that labor market institutions compress the wage distribution in OECD countries. The evidence on their effect on employment, however, is mixed.

We assume that the minimum wage does not change over time. This implies that innovations indeed can redistribute factor income back from labor to the intermediate good. For an analysis of exogenous wage *growth* on innovation see Bester and Petrakis (2001) and Hellwig and Irmen (2001) and their references.

3.4 Numerical Illustration

We now want to present numerical results for the thought experiments of the Remarks above. Table 1 displays the parameter values of the benchmark case.

Table 1: Parameter Values for Benchmark Case

$\beta = 1$	$\alpha_1 = .8$
$\overline{r} = .08$	$\alpha_2 = .8$
$\xi = .1$	$\gamma = 1.2$
$P = 1$	

We set $\beta = 1$ so that the cost of innovation is $\frac{q^2}{2}$. The interest rate $\overline{r}$ is set to .08 which is consistent with stock market returns in the last fifty years. We pick an imitation rate ξ of .1. Since we consider very large innovations we parametrize γ as 1.2 which means that a technology laggard needs 20% more inputs to produce the same output. We set $\alpha_1 = \alpha_2 = .8$ and the relative price of the final good using skilled labor P equal to 1 so that the two final and intermediate-good sectors are perfectly symmetric.

Table 2 displays the numerical results for research efforts, implied growth rates and wage differentials. Note that the wage differential depends on the relative position on the technology frontier in the intermediate-good sector which determines the price of the intermediate good. Instead of presenting three different wage differentials for each technology status we use the aggregate price of the intermediate good $p_i = (\lambda_{ai} + \lambda_{bi})/(x_{ai} + x_{bi})$. This a weighted average of the price where the weight is the relative output of each firm. We get two wage differentials for the state with a technology leader and laggard in the market and for the state with neck-and-neck firms, respectively. We prefer this measure because the constant-returns-to-scale assumption in the final-good sector leaves the size of firms indeterminate. Hence, we prefer to aggregate as if their were one big firm instead of deriving a range of wage differentials. The actual value would then depend on the firm-size distribution.

As a result of perfect symmetry in the benchmark case, column 1 in Table 2 shows that research efforts and growth rates are the same in both intermediate-good sectors. Note that the research effort of the technology leader is zero because we analyze the case of very large innovations. The wage differential between skilled and unskilled workers is 1 because the price of both intermediate goods is the same and so are the parameters of the production functions in both final-good sectors. Of course, this perfect symmetry is not realistic but it is useful in order to facilitate comparison of the numerical results in the different scenarios.

In Scenario A we let the price of the final good using unskilled labor fall to .8 so that $P = 1.25$. As pointed out in Remark 1, column 2 in Table 2 shows that R&D efforts for the intermediate good used with unskilled labor become smaller relative to R&D efforts for the intermediate good used with skilled labor. This results in a smaller growth rate in the first intermediate-good sector. Moreover, the wage differential increases resulting from the standard Stolper-Samuelson effect. This effect is mitigated by the second-order effect that the price of the intermediate good used together with unskilled labor is lower because it is demanded less. Hence, the intensity of labor is smaller in the final-good sector using unskilled labor which leads to a higher marginal productivity and thus also a higher wage. Since in Scenario A the difference in the price of the intermediate good is larger if firms are neck-and-neck than in the case of a technology leader and laggard, the wage differential is slightly higher in the former case.

In Scenario B $\alpha_1 = .8$ and $\alpha_2 = .2$, i.e., there is more competition for the intermediate good used with unskilled labor. As stated in *Remark* 3, column 3 in Table 2 shows that there is more R&D for the intermediate good used with unskilled labor and the wage differential decreases compared to the benchmark case. The smaller price for the intermediate good used with unskilled labor increases the wage of the unskilled relative to the skilled.

Note that the intermediate-good sector 1 is not affected by Scenario B and intermediate-good sector 2 is not affected by Scenario A. Thus, it follows from columns 2 and 3 that an increase of the relative price of the skill-intensive good combined with more competition for the intermediate good used with unskilled labor can induce defensive innovations as pointed out in Remark 4 (compare the results of column 2 for the intermediate-good sector 1 with column 3 for the intermediate-good sector 2).

In Scenario C we set $w^{\min}$ so that for the chosen parameter values it is binding for technology laggards, but not for neck-and-neck firms and the technology leader. Compared to the benchmark case, R&D efforts for both intermediate goods increase substantially (see column 4 in Table 2). The results for the intermediate good used together with skilled labor are the same because having assumed complete symmetry the skilled wage is equal to the unskilled wage. Thus, the wage differentials remain unchanged compared to the benchmark case.

In Scenario D we combine Scenario A and C. The intermediate-good sector producing for the final-good sector using skilled labor is now unaffected since the higher relative price makes the minimum wage no longer binding. On the contrary, the minimum-wage constraint is more binding for the first intermediate-good sector than in Scenario C because of the fall of the final-good price in sector 1. The minimum wage now imposes pricing constraints on technology laggards and neck-and-neck firms producing the intermediate good used together with unskilled labor. In the first intermediate-good sector R&D efforts increase compared to Scenario A, and the growth rate increases even compared with the benchmark case (see column 5 in Table 2). I.e., the growth rate is higher in the intermediate-good sector whose output is used together with unskilled labor in the final production stage. Hence, as stated in Remark 5 openness, i.e., a fall in the relative price of the final good using unskilled labor, can induce defensive innovations in the presence of labor market institutions such as minimum wages. Note, that intuitively the wage differential is more compressed than in Scenario A. After providing numerical illustrations of our results we now turn to further empirical implications.

3.5 Empirical implications

The results of Remark 3 imply that defensive innovations have the potential to explain why the actual trade volumes between developed and less-developed countries are small and wage differentials have not increased as much as one would have expected. The model presented above also has an interesting dynamic implication for the final-good industry structure. If we define aggregate output as $Y = P_1F_1 + P_2F_2$, then

$$g_Y = \frac{1}{2}\left[\omega_1 g_1 + \omega_2 g_2\right] \ , \tag{23}$$

where $\omega_i \equiv \frac{P_i F_i}{Y}$ is the sector share, g_Y is the growth rate of aggregate output and g_i, $i = 1, 2$, is the growth rate of output in the intermediate-good sector i. We know from above that the growth rate of the final-good sector is $g_i/2$ for our parametric specification of the production functions in the final-good sectors. Equation (23) shows that the aggregate growth rate will change not only as the growth rates of the intermediate sectors change, but also as the sector shares change. By definition $\frac{\dot{\omega}_i}{\omega_i} = \frac{1}{2} g_i - g_Y$. I.e., not surprisingly the sector which grows relatively more will have an increasing share of the economy's output. Hence, strictly applied our model implies that in countries with defensive innovations the sector share of the final-good sector using unskilled labor converges to 1. A weaker and probably more realistic prediction is the following.

Remark 6 *If a higher minimum wage induces more defensive innovations, countries with higher minimum wages produce a larger share of output in the final-good sector using unskilled labor.*

This follows directly from the previous sections. Defensive innovations imply relatively more growth in the sector using unskilled labor. We now try to retrieve the prediction of Remark 6 in the data.

4 Empirical evidence

Since we are interested in the effects of openness in developed countries, we use data for OECD countries. Unfortunately, data on tariffs and non-tariff trade barriers are not available for a long enough time period. Standard openness indicators which are based on trade volumes are problematic because trade volumes are clearly endogenous in our modeling framework. Hence, we take as given that OECD countries became more open in the sample period which is a well documented fact (see, e.g., OECD (1997a)). As long as differences in openness between countries remain constant over time, these will be controlled for by the country fixed effects in the estimation.

Due to data availability our sample is an unbalanced panel of 9 OECD countries and 13 subsectors within the manufacturing industry for 1975-91 (see the note of Table 3 for details on the sample and data sources). For the sector shares we use total manufacturing GDP as a normalization instead of total GDP. This is done because we do not want changes in the importance of traded versus non-traded goods –which are outside our model's perspective– to influence our results. Because industries within the manufacturing sector are heterogenous with respect to the used factor intensities, enough variation remains. We use non-production workers as a proxy for skilled workers because data on production workers are available at an annual frequency. Because minimum wages are only one reason for downward wage rigidity and other labor market institutions such as unions are likely to induce wage floors, we use aggregate unit labor cost as a more general empirical measure for deviations of the cost of labor from its productivity.

The question we want to address is how sectors which have different factor intensities are affected by relative unit labor cost in open economies. E.g., is the textile industry relatively more important in Italy than in the US (as measured by the sector's share) because the textile industry is more capital intensive in Italy and is thus less affected by competition with less-developed countries? Does high unit labor cost have an adverse effect on a sector's importance, is the opposite the case because of defensive innovations, and how does this depend on the skill and capital-intensity of the sectors?

In our estimations we control for industry, country and time effects. We use a log-linear specification because the relationship between the sector share and factor intensities and labor cost is non-linear in the model even for simple functional forms.[11] The semi-structural evidence summarized in Table 3 suggests that the share of sectors is relatively higher in developed countries if they are capital or skill-intensive already at the beginning of the sample period. The elasticity of the

[11] Heckscher-Ohlin type trade models predict that factor endowments matter for sector shares. See, e.g., Harrigan (1997) and Redding (2001) for empirical evidence that factor endowments matter for the production structure in OECD countries. In our empirical exercise we consider factor intensities per sector which proxy technology. Differences in factor endowment are picked up by the country fixed-effects. Given that we have a sample of OECD countries which are relatively abundant in skilled labor and capital compared to less-developed countries, differences in factor endowments compared with less-developed countries imply that a sector which produces with a higher skill- or capital-intensity should be relatively larger.

sector share with respect to the skill (*lnnprat*) and capital (*lnklrat*) intensity is positive and more significant for the latter. This is not surprising since developed countries will produce relatively more of the good for which they have a comparative advantage. Additional capital deepening leaves the sector share unchanged, i.e., the coefficient of the growth rate of the capital-labor ratio is not significant. Upskilling, however, seems to have a small negative effect which is only significant on the 8%-level, however.

Let us now turn to the results for unit-labor cost which are the main interest of the empirical exercise. Interestingly, higher unit-labor cost are *positively* related to the sector share. However, this effect is dampened the more skill- or capital-intensive is the sector. This is consistent with the interpretation that part of the reason why, e.g., the textile sector is larger in Italy than in the US (controlling for factor intensities) is that labor is more costly in Italy. The reason might be that high unit labor cost induces defensive innovations which increase the sector share *ceteris paribus.* Note that this effect becomes smaller the higher the skill or capital-intensity (the sign of the coefficients of the interaction terms is negative). Again this is consistent with our model because higher unit labor cost induces less innovations in sectors which are less intensive in unskilled workers.

The empirical result is surprising. Straightforward intuition would suggest that higher unit labor cost has a negative effect on the sector share. Moreover, one would expect that higher unit labor cost favors skill and capital-intensive industries. The results can be explained with our model and suggest that defensive innovations indeed might be relevant (see Remark 6).

Our results are related to empirical evidence provided by Nickell et al. (2001) who find that employment protection hampers sectorial *adjustment.*[12] If unit labor cost and employment protection are positively correlated this could be an alternative explanation. However, employment protection measures have not changed much over time so that they should be captured to a large extent by the country fixed effects. Another explanation of the empirical evidence might be that the more important a sector, the more decisive it is in bargaining process determining the wage. The

[12] Our model and the suggestive empirical evidence imply that labor market institutions might affect the economy's steady state.

proportion of unskilled workers in a sector might amplify this effect if union density is relatively high in these sectors. Hence, the positive correlation of unit labor cost with the sector share and the negative correlation with the interactions of skill and capital intensity might be spurious.

To get an impression whether endogeneity indeed matters we use five-year lags of the regressors. Table 4 displays the results. The coefficients and significance of the regressors of interest remain qualitatively unchanged. Interestingly, the point estimate of unit labor cost even increases. These results suggest that endogeneity is unlikely to substantially affect the results obtained in the previous regression.

Finally, our results could be spurious if the relative degree of openness between countries varies over time. One might guess that labor market regulations are highly correlated with export and import regulations. Then our empirical finding might pick up nothing else, but that the countries which are more regulated, i.e., have a high unit labor cost and are relatively less open, produce relatively more in the unskilled-labor intensive sector. To get a first impression whether this is a serious problem we calculate the correlation between unit labor cost and average ad-valorem tariffs for OECD countries using data on tariffs for the years 1988, 1993 and 1996.[13] The correlation between the two variables is positive but not significant for all standard significance levels. This suggests that our results are not picking up effects of differences in openness between countries.

5 Conclusions

Understanding potential interactions between openness, labor market structures and technology changes is important to ultimately assess the effects of openness on wage distributions, trade volumes and unemployment. If these interactions are considered important, openness does not have necessarily a big effect on labor markets and trade volumes if technology changes mitigate or even offset the effects of openness. Introducing the idea of step-by-step innovations into a standard Heckscher-Ohlin model, we show that openness can induce defensive innovations in developed

[13] Data on tariffs are from the OECD (1997b).

countries through competition, imitation or labor market institutions. In particular, we find that labor market institutions such as minimum wages can be an important determinant of the effects of openness on innovations, and thus factor prices and trade volumes. The empirical evidence we provide suggests that defensive innovation indeed might be important in OECD countries. To be confident about the results, however, better data is needed to improve identification of the forces at work. Finally, it would be interesting to endogenize institutions in future research. E.g., Acemoglu et al. (2001) argue that skill-biased technology change might have fostered deunionization.

Appendix

A Proof of Remark 1

From (8) it follows immediately that $\frac{\partial \pi_{i,k}}{\partial M_i} = \frac{\partial \pi_{i,k}}{\partial \lambda_{i,k}} \frac{\partial \lambda_{i,k}}{\partial M_i} > 0$, $k \in \{-1, 0, 1\}$. Since M_1 falls and M_2 increases as production is shifted towards the sector using skilled labor, profits of firms in the first sector fall whereas profits of firms in the second sector increase. Because

$$\frac{p_{ji}^{\frac{\alpha_i}{\alpha_i - 1}}}{p_{ai}^{\frac{\alpha_i}{\alpha_i - 1}} + p_{bi}^{\frac{\alpha_i}{\alpha_i - 1}}}$$

$j = a, b$, $i = 1, 2$, is larger the more advanced the firm on the technology frontier, equation (6) implies that profits of firms more advanced on technology frontier are more sensitive to changes in M. Hence, the fall of M_1 implies that $\pi_{1,1} - \pi_{1,0}$ and $\pi_{1,0} - \pi_{1,-1}$ decrease whereas the increase of M_2 implies that $\pi_{2,1} - \pi_{2,0}$ and $\pi_{2,0} - \pi_{2,-1}$ increase. Equations (17) and (18) then imply that $q_{2,0}$ and $q_{2,-1}$ increase whereas $q_{1,0}$ on $q_{1,-1}$ decrease.

Equation (18) shows that the direct effect of changes in $\pi_{i,0} - \pi_{i,-1}$ might be offset by the indirect opposite effect of $q_{i,0}$ on $q_{i,-1}$. For marginal changes the direct effect will always be stronger than the indirect effect applying the envelope theorem.$\blacksquare$

B Proof of Remark 2

a) This part is already contained in Aghion et al. (2001). We repeat the main argument for completeness and refer to their paper for further details.

We already know that R&D effort positively depends on relative profits. Hence, it remains to be shown that relative profits increase. As noted above technology leaders do not exert any effort in the case of very large innovations. Hence, it remains to be shown that R&D effort increase for neck-and-neck firms and technology laggards. It is shown in Aghion et al. (2001), Remark 1 that for $\pi(z, \alpha)$, $\pi(z, 0) = 1/2$. Hence, if there is no competition, i.e., $\alpha = 0$, firms' profits do not depend on technology and thus the research effort will be zero. In particular, $\pi_1 - \pi_0 = \pi_0 - \pi_{-1} = 0$. If some competition is introduced instead, profits are decreasing in z. For neck-and-neck firms

$$\frac{\partial \pi}{\partial z}|_{z=1} = -\frac{\alpha}{4-\alpha^2}.$$

Hence, the introduction of competition yields $\pi_1 - \pi_0 > 0$ and $\pi_0 - \pi_{-1} > 0$. Equations (17) and (18) and the envelope theorem already mentioned in the previous proof imply $q_0 > 0$, $q_{-1} > 0$. Because sector 1 and 2 are symmetric in the Scenario considered, research efforts will increase by the same amount.

b) We know that $q_{1,-1} = q_{2,-1}$ and $q_{1,0} = q_{2,0}$. Then equation (19) implies that both sectors grow at the same rate so that the sector shares remain unchanged. It follows from equation (22) that trade volumes per output remain unchanged as well.

c) Since both intermediate-good sectors grow at the same rate, both prices of the intermediate good fall at the same rate. Equation (20) then implies that the wage differential remains unchanged.■

C Proof of Remark 6

A necessary condition for the minimum wage to affect only the first final-good sector which uses unskilled labor, is $P > 1$. Equation (20) then implies that skilled wages are larger than unskilled wages. We want to show that a minimum wage can increase the research effort in the sector producing the intermediate good used with unskilled labor. It follows from equations (17) and (18), that all we need to show is that the relative profits $\pi_{1,0} - \pi_{1,-1}$ and $\pi_{1,1} - \pi_{1,0}$ increase.

Equations (1) and (3) imply that if there is a binding minimum wage, the return to the intermediate good r_1 must be smaller for the final-good sector one to break even. The final-good sector using unskilled labor can pay a maximum price $p^{\max}$ for the intermediate good:

$$p^{\max} = \frac{P_1}{4w^{\min}} \ ,$$

where $w^{\min}$ is defined in terms of good 1, i.e., $w^{\min} = \frac{W^{\min}}{P_1}$. The choice of the numeraire is not crucial for the results. Note that the maximization problem of the firm in the intermediate-good sector 1 has an additional constraint $p \leq p^{\max}$. Equation (7) implies that in the unconstrained case $p^u_{1,1} < p^u_{1,0} < p^u_{1,-1}$, where $p^u_{i,k}$ is the price of an unconstrained firm in sector i with technology status k. Technologically more advanced firms have smaller marginal cost. However, λ depends negatively on z. Having relatively higher revenues a technology leader has a lower elasticity of demand (see equation (5)) and thus charges higher prices ceteris paribus. This indirect effect will not outweigh the direct effect for marginal changes due to the envelope theorem.

We have to distinguish three cases to characterize profits and revenues:

a) the minimum wage is binding for all firms in sector 1.

b) the minimum wage is binding for the technology laggard and the neck-and-neck firms in sector 1.

c) the minimum wage is binding only for the technology laggard in sector 1.

to a): From equation (6) it follows that $\lambda_{1,k} = \frac{1}{2}M_1$, $k \in \{-1, 0, 1\}$. Profits change to

$$\pi_{i,k} = (1 - \frac{\rho_{1,k}}{p^{\max}})\frac{M_1}{2}. \tag{24}$$

If the constraint is binding for all firms, $p_{1,k} = p_1^{\max}, k = -1, 0, 1$. The constraint is most binding for the laggard and least binding for the leader. I.e., $p_{1,1}^u - p_1^{\max} < p_{1,0}^u - p_1^{\max} < p_{1,-1}^u - p_1^{\max}$. Hence, equation (24) implies that relative profits $\pi_{1,0} - \pi_{1,-1}$ and $\pi_{1,1} - \pi_{1,0}$ increase although absolute profits fall. Note that for marginal changes the envelope theorem implies that we can neglect the changes in revenues. For discrete changes in revenues this need no longer hold since $\lambda_{1,-1}$ increases and $\lambda_{1,1}$ decreases to $\frac{M_1}{2}$. Moreover, note that we still assume $q_{1,1} = 0$ although with binding minimum wages there is an incentive for the technology leader to innovate in order to mitigate the constraint. Allowing $q_{1,1} > 0$ would further increase R&D efforts and growth in the final-good sector using unskilled labor.

to b): Neck-and-neck firms are characterized as in a). The technological leader's profits are determined as in equation (8) whereas the profits of the technology laggard are

$$\pi_{i,k} = (1 - \frac{\rho_{1,k}}{p^{\max}})\lambda_{1,-1},$$

where $\lambda_{1,-1} = M_1 - \lambda_{1,1}$ which is determined implicitly by the following equation:

$$\lambda_{1,1} = \frac{\left(\frac{1-\alpha_1\lambda_{1,1}}{\alpha_1(1-\lambda_{1,1})}\right)^{\frac{\alpha_1}{\alpha_1-1}}}{\left(\frac{1-\alpha_1\lambda_{1,1}}{\alpha_1(1-\lambda_{1,1})}\right)^{\frac{\alpha_1}{\alpha_1-1}} + \left(p^{\max}\right)^{\frac{\alpha_1}{\alpha_1-1}}} > \frac{M_1}{2}.$$

As in a) relative profits increase compared with the unconstrained case where $\pi_{1,0} - \pi_{1,-1}$ and $\pi_{1,1} - \pi_{1,0}$ increase even more compared with a) because revenues of the technology leader increase and those of the laggard decrease. This is not surprising because the technology leader now solves an unconstrained maximization problem and benefits from the fact that the technology laggard is constrained.

to c): Neck-and-neck firms' profits and revenues are as in the unconstrained case. The technology laggard's and leader's revenues and profits are as in b). From b) it follows that relative profits increase compared to the unconstrained case.■

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Table 2: Numerical Comparative Statics

Intermediate Sector 1 (producing for final good sector using unskilled labor)

	Research Effort				
Scenario	*Benchmark*	*A*	*B*	*C*	*D*
Techn. Laggard	0.641	0.491	0.641	1.150	0.809
Neck-and-Neck Firm	0.927	0.687	0.927	1.242	0.807
Techn. Leader	0.000	0.000	0.000	0.000	0.000
Growth Rate	0.097	0.075	0.097	0.152	0.106

Intermediate Sector 2 (producing for final good sector using skilled labor)

	Research Effort				
Scenario	*Benchmark*	*A*	*B*	*C*	*D*
Techn. Laggard	0.641	0.641	0.264	1.150	0.641
Neck-and-Neck Firm	0.927	0.927	0.333	1.242	0.927
Techn. Leader	0.000	0.000	0.000	0.000	0.000
Growth Rate	0.097	0.097	0.043	0.152	0.097

Final Good Sectors

	Skilled-Unskilled Wage Differential				
Scenario	*Benchmark*	*A*	*B*	*C*	*D*
Neck-and Neck in interm.-good sector	1.000	1.476	0.167	1.000	1.302
Laggard-Leader in interm.-good sector	1.000	1.461	0.166	1.000	1.292

Benchmark: Symmetric Case

Scenario A: Fall in the relative price of the final good using unskilled labor

Scenario B: Decrease in competitiveness in the intermediate good sector 2

Scenario C: Binding minimum wage

Scenario D: Scenario A and Scenario C

Table 3: The effect of unit labor costs on sector shares within the manufacturing sector in OECD countries 1975-91

	Estimation with country fixed-effects		
Dep. Variable	*log(sector share): GDP-share per sector of total manufacturing GDP*		
# observations	987		
R2 within	0.6727		
	coeff.	**t-value**	**P-value**
lnnprat: log(initial ratio of non-production over production workers)	1.26	1.62	0.11
growth rate of the ratio of non-production over production workers	-0.35	-1.77	0.08
lnklrat: log(initial capital-labor ratio in 1985 $)	1.84	3.8	0.00
growth rate of the capital-labor ratio	-0.22	-0.72	0.47
lnulc: log(relative unit labor costs compared with US)	2.23	1.91	0.06
interaction of lnnprat and lnulc	-0.21	-1.29	0.20
interaction of lnklrat and lnulc	-0.22	-2.12	0.03
constant	-22.92	-4.13	0
Time dummies	Yes		
Industry Dummies	Yes		

Note: Due to data availability the sample is an unbalanced panel of the following OECD countries for 1975-91:
Belgium, Denmark, Finland, Germany, Italy, Norway, Sweden, UK, USA; and the following sectors with the ISIC definitions in brackets: food (31), textiles (32), wood (33), paper (34), chemicals (35), minerals (36), primary metals (37), metals (381), non-elec. machinery (382), electrical machinery (383), shipbuilding (384), professional (385).
Data on unit labor cost are obtained from the OECD Statistical Compendium. The data on the capital stock and GDP in 1985 $ are from the ISDB database provided by the OECD. Data on production and non-production workers are from the UNISD database provided by the UN. See Redding (1999) and his references for further details.

Table 4: The effect of unit labor costs on sector shares within the manufacturing sector in OECD countries 1980-91 using 5-year lags of regressors

	Estimation with country fixed-effects		
Dep. Variable	*log(sector share): GDP-share per sector of total manufacturing GDP*		
# observations	602		
R2 within	0.7119		
	coeff.	**t-value**	**P-value**
lnnprat: log(initial ratio of non-production over production workers)	1.07	1.05	0.30
growth rate of the ratio of non-production over production workers	0.09	0.24	0.81
lnklrat: log(initial capital-labor ratio in 1985 $)	2.74	3.74	0.00
growth rate of the capital-labor ratio	-0.34	-0.81	0.42
lnulc: log(relative unit labor costs compared with US)	4.16	2.37	0.02
interaction of lnnprat and lnulc	-0.17	-0.82	0.41
interaction of lnklrat and lnulc	-0.40	-2.65	0.01
constant	-32.30	-3.80	0.00
Time dummies	Yes		
Industry Dummies	Yes		

Note: Due to data availability and five-year lags the sample is an unbalanced panel of the following OECD countries for 1980-91:
Belgium, Denmark, Finland, Italy, Norway, Sweden, UK, USA; and the following sectors with the ISIC definitions in brackets:
food (31), textiles (32), wood (33), paper (34), chemicals (35), minerals (36), primary metals (37), metals (381), non-elec. machinery (382), electrical machinery (383), shipbuilding (384), professional (385).
Data on unit labor cost are obtained from the OECD Statistical Compendium. The data on the capital stock and GDP in 1985 $ are from the ISDB database provided by the OECD. Data on production and non-production workers are from the UNISD database provided by the UN. See Redding (1999) and his references for further details.

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