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ABSTRACT

The Effects of Globalization on Worker Training*

We examine how globalization affects firms' incentives to provide general worker training. We consider a three-stage game. In stage 1, firms invest in productivity-enhancing training. In stage 2, they can make wage offers for each others' workers. Finally, Cournot competition takes place. When two product markets become integrated, that is, replaced by a market with greater demand and more firms, training by each firm increases, provided the two markets are sufficiently small. When barriers between large markets are eliminated, training is reduced. Integration increases welfare if it does not reduce training. However, for large parameter regions, welfare falls if integration reduces training. We also show that opening markets to countries with publicly funded training or cheap, low-skilled labour can threaten apprenticeship systems.

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1 Introduction

Though simple theory suggests otherwise, many empirical studies show that firms finance a considerable part of general worker training. However, firms are becoming less inclined to do so, for instance, in Germany. Several authors have put forward convincing explanations, such as demographics and compositional factors, for these changes.[1]

Our paper offers an alternative explanation: There is a close link between product market integration and firms' incentive to invest in worker training. Two simple ideas are the basis for this hypothesis. First, we think of general training expenses as cost-reducing investments, as training increases worker productivity. Second, when product markets are imperfectly competitive, their integration should increase competition, as each firm faces more competitors. Thus, as a first approximation, the relationship between integration and general training should resemble the relationship between the intensity of competition and incentives for cost-reducing investments, which has been discussed extensively in industrial organization and growth theory.[2]

However, this analogy is misleading in some ways. First, while integration increases the number of competitors for each firm, it also increases the size of the market. As greater market size corresponds to less intensive competition, it is not entirely obvious that integration corresponds to greater competition. Second, if a worker leaves a firm, the competitor can use his general knowledge. Thus, training expenses resemble cost-reducing investments with potential spillovers to competitors. Third, when a firm loses a worker, the training expenses are entirely worthless for the original employer. This contrasts with an innovating firm that can still use its innovation even when there are knowledge spilloveers to the competitor. Our analysis accounts for these complications.

[1]See, for example, Euwals and Winkelmann 2001, Franz and Soskice 1995, Büchel 2002.

[2]A large literature discusses the relationship between the number of firms and innovation incentives. Scherer and Ross (1990, ch. 17) and Motta (2004, ch. 2.4) provide introductions to the subject.

We analyze two cases, the immobile worker model and the mobile worker model. In both models, we consider the integration of two national product markets, each of which is a Cournot oligopoly. A training stage, in which each firm decides whether to train its workers precedes product market competition. Firms that have trained their workers have lower marginal production costs than those that have not, as their workers are more productive. In both cases, we consider the effects of market integration: An integrated market is described by the same model as the national markets, except that the number of firms and the market demand are now the sums of the corresponding quantities for each country.

In the *immobile worker model*, workers are not allowed to change employers. The game only consists of the training stage and product market competition. In the *mobile worker model*, there is an interim stage where firms bid for each others' workers. The effects of product market integration on training incentives are similar in both cases. First, suppose the two countries have small product markets, meaning that the number of firms and market demand are both small. Then, integration increases training incentives; and, for suitable parameter values market integration leads to a training equilibrium where none existed under autarky. If the two product markets are sufficiently large initially, market integration will destroy the training equilibrium.

The effects of integration on welfare are striking. Integration has unambiguously positive effects on welfare if it does not affect training decisions. If integration induces a training equilibrium, then this statement still holds. However, if integration destroys the training equilibrium, welfare falls for a large set of parameters. Intuitively, even though integration reduces markups and leads to savings in training costs, the negative welfare effects due to lower productivity dominate.

In addition to product market integration, we also consider labor market integration. At first glance, when workers face more options concerning future employers, the willingness of firms to train their workers should be reduced. However, we show that, at least in our setting, labor market integration usually has no effect on training decisions.

We also apply our analysis to countries facing competition in product markets from countries that have competing training systems. For example, countries with apprenticeship systems, such as Germany, face competition by firms from countries with vocational schooling systems or countries with low-skill workers who have little or no training. We show that such competition is indeed a threat to apprenticeship systems: The negative effects of globalization on training are more pronounced than when countries are symmetric.

There is some other literature on the relation between globalization and human capital accumulation. Existing theoretical papers concentrate on *workers'* incentives to acquire human capital, arguing that globalization affects both workers' returns to education and its costs.[3] In contrast to this literature, our focus is on *firms'* incentives for training. In this respect, our paper relates to theories explaining why firms invest into general training at all, even though, according to Becker (1964) and Mincer (1974), at least in competitive labor markets, they should have no incentive to bear the costs of general training, as the associated rents accrue exclusively to the employees.[4] This literature does not, however, discuss the role of product market competition or globalization on training decisions.[5]

[3]Cartiglia (1997) emphasizes that, because trade has income effects, it changes the liquidity constraints that workers are facing, and thus their ability to invest into education. Further, he notes that by increasing the relative wages of skilled workers, trade openness increases the costs of education. Rodrik (1997) argues that uncertainty about sector-specific shocks brought about by globalization may reduce the incentives to acquire sector-specific skills. General human capital investment, on the other hand, allows workers to adjust easily to sectoral shocks (Kim and Kim, 2000).

[4]Examples include Katz and Ziderman (1990), Chang and Wang (1995, 1996), Abe (1994), Prendergast (1992), Glaeser (1992), Acemoglu (1997) and Acemoglu and Pischke (1998). Acemoglu and Pischke (1999) provide an insightful survey of the arguments.

[5]Gersbach and Schmutzler (2003) consider the effects of product market competition on training incentives in a duopolistic setting: To analyze the effects of globalization, we

The paper is organized as follows. Section 2 analyzes the model with immobile workers. Section 3 introduces the model with mobile workers, and provides reduced form conditions for training equilibria. Section 4 analyzes how globalization, that is, labor and/or product market integration affects the chances that training equilibria arise. In Section 5 we explore the effects of globalization on welfare and distribution. Section 6 extends the analysis to countries with asymmetric training systems. Section 7 concludes and discusses extensions.

2 The Model with Immobile Workers

We shall consider different models to capture different degrees of product market integration and worker mobility. We first introduce the *Training Game with Immobile Workers* (IWG), which merely serves as a reference model. For this purpose, it is useful to work with the simplifying assumption that training is a zero-one decision, even though the immobile worker case could easily be generalized to a continuous training decision.[6]

The model should be thought of as representing either one national market that is completely closed or as the model of a fully integrated world market. In period 1, firms $i = 1, ..., I$ $(I \geq 2)$ simultaneously choose their general human capital investment levels $g_i \in \{0, 1\}$.[7] Marginal costs c_i are a decreasing functions $c(g_i)$ of the number of trained workers in a firm. Training costs are $T > 0$ for a firm.[8]

In period 2, the I firms are Cournot competitors, producing homogeneous

have to extend their model to arbitrary firm numbers.

[6]Vives (2003) considers several related continuous models to show how competitive pressure affects (cost-reducing) innovation.

[7]It is best to think of firms as either having one worker each or a team of workers such that their human capital investments are perfect complements, i.e., education is only valuable if the entire team is educated.

[8]We interpret training costs in a broad sense. They consist of all expenses to upgrade the skills of workers, including any measures to motivate workers to acquire skills.

goods, with inverse demand $p = a - bx$, where $b = \frac{B}{I}$, where x is output, p is price and a and B are positive constants. Note the dual role of I here. It is not only the firm number, but also a measure of market size. This is convenient for analyzing the effects of market integration: For instance, when two identical countries integrate, both the firm number and the market size double.

Recall the standard result that profits in a Cournot oligopoly with inverse demand $p = a - b \cdot x$ $(b > 0)$ and marginal costs $(c_1, ..., c_I)$ are

$$\pi_i = \frac{1}{b\,(I+1)^2}\left(a - Ic_i + \sum_{j \neq i} c_j\right)^2. \tag{1}$$

Also, for later reference, note that the equilibrium price is

$$p = \frac{1}{(I+1)}\left(a + \sum_{j=1}^{I} c_j\right). \tag{2}$$

To illustrate our results, we use the specific training technology.[9]

$$c_i\,(g_i) = \frac{c}{\delta g_i + 1} \text{ for some } \delta > 0, g_i \in \{0, 1\}\,. \tag{3}$$

Using (1) and (3), profits of firm i are:

$$\pi_i\,(g_i, G) = \frac{I}{B\,(I+1)^2}\left(a - \frac{cI}{\delta g_i + 1} + \frac{(G - g_i)c}{\delta + 1} + (I - 1 - G + g_i)\,c\right)^2 \tag{4}$$

where G is the total number of firms who train their workers.

We give conditions for a symmetric *training equilibrium* where all firms train one worker. The following notation describes the *training incentives* for a firm when all its competitors also train their workers:

$$\Delta\pi \equiv \pi_i\,(1, I) - \pi_i\,(0, I-1)\,.$$

The following result is obvious.

[9] We assume that the marginal costs are lowered by trained individuals for the entire range of quantity choices that are relevant for the derivation of equilibria. The assumption requires that high- and low-skilled workers are complementary in the production process (see Teulings 2000 and Acemoglu 2001).

Proposition 1 *A training equilibrium of the IWG with $g_i = 1$, $i = 1, ..., I$ exists if and only if*

$$\Delta\pi = \pi_i (1, I) - \pi_i (0, I - 1) \geq T.$$

Applying (4), it is straightforward to show that

$$\Delta\pi = \frac{\delta c I^2}{B (I + 1)^2 (1 + \delta)^2} \{2(a - c) (1 + \delta) - (I - 2) \delta c\} . \tag{5}$$

As (5) is an inverted U-shaped function of I, a greater value of I has a positive effect on training incentives if the initial value of I is sufficiently low, and a negative effect if the initial value is sufficiently high.

Corollary 1 *In the IWG, as I increases, the range of parameters a, δ, B, c for which a training equilibrium exists first increases, then decreases.*

Proof. Simple calculations show that

$$\frac{\partial (\Delta\pi)}{\partial I} = \frac{\delta c I}{B (I + 1)^3 (1 + \delta)^2} \left[\delta c \left(4 - 3I - I^2\right) + 4 (a - c) (1 + \delta)\right],$$

which is positive if and only if

$$\delta c \left(4 - 3I - I^2\right) + 4 (a - c) (1 + \delta) > 0.$$

There is a unique $I^* > 0$ for which the left-hand side is 0. For $I \rightarrow 0$, the left hand side is positive; for sufficiently large I it is negative. ■

Figure 1 plots $\Delta\pi$ as a function of I for $a = 10$, $c = 1$, $B = 1$, $\delta = 0.9$. The figure shows how the effects of globalization on training depend on the initial number of firms in each country. If firm numbers in each country are I_k $(k = 1, 2)$, the pre-integration equilibrium in country k corresponds to I_k, whereas the post-integration equilibrium corresponds to $I_1 + I_2$. Suppose that, as in Figure 1, $T = 5$. Then, if $I_1 = I_2 = 3$, there will be no training equilibrium in either country, as $\Delta\pi < T$. After product market integration, there are six firms in the market, with twice the market size of each country.

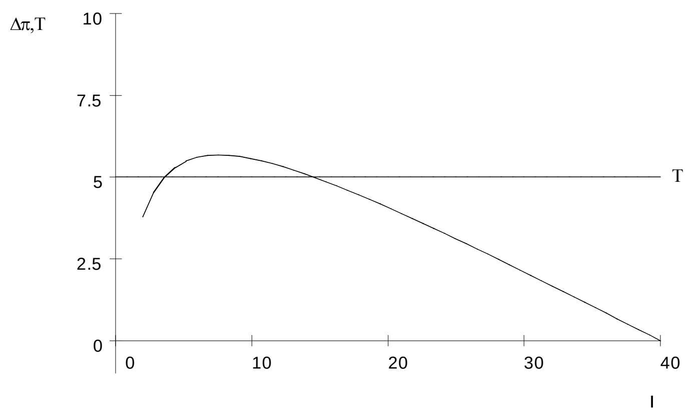

Figure 1: Training Incentives with Immobile Workers

Now $\Delta\pi > T$, so that the training equilibrium exists. Hence, globalization creates a training equilibrium. On the other hand, suppose there is a relatively high number of firms in each country, for example, $I_1 = I_2 = 10$. Then, there is a training equilibrium before integration. After integration, there are 20 firms in the world industry, and the corresponding training incentive satisfies $\Delta\pi < T$. Thus, in this case, globalization destroys the training equilibrium.

This example illustrates a principle that occurs repeatedly in this paper: If the two countries (i.e., their firm numbers and market sizes) are small, the beneficial effects of integration on training that come from greater market size dominate over the negative effects from greater competition.[10] For greater initial market sizes, the training equilibrium is destroyed when product market integration takes place.

[10] To isolate the effects of increasing market size and increasing firm number, consider a model with firm number I^F and market size I^M. Suppose $c_j = \frac{c}{1+\delta}$ for all $j \neq i$. Expression (1) becomes $\pi_i = \frac{I^M}{B(I^F+1)^2}\left(a - I^F c_i + \sum_{j=1, j\neq i}^{I^F} c_j\right)^2$. Thus, $\Delta\pi$ is always increasing in I^M, but decreasing in I^F when $c_i > \overline{c}$.

3 Mobile Workers

Worker mobility can potentially affect the relationship between globalization and training through two channels. First, even mobility *within* countries is likely to affect training behavior, because firms have to take the possibility into account that competitors might poach trained workers. As this possibility tends to reduce training levels both before and after integration, it is thus unclear without further analysis how intra-country mobility influences the effects of product market integration on training. Second, mobility *between* countries is in itself worthy of study. How does such mobility affect training incentives? Intuitively, training incentives might be reduced, because firms face a greater danger that competitors can poach trained workers. We check whether this intuition is correct.

3.1 The Game Structure

We analyze these issues in the *Training Game with Mobile Workers* (MWG), which involves three periods. In period 1, firms take training decisions $g_i \in \{0, 1\}$. In period 2, after having observed each others' training decisions, firms simultaneously make wage offers for each others' workers. Thus, each firm $i \in \{1, ..., I\}$ makes a list of wage offers $w_{ij}, j \in \{1, ..., I\}$ for all of the trained workers in the market.[11] If $g_j = 0$, wages will be $w_{ij} = 0$, $i = 1 \ldots I$. Thus, (i) we normalize the wages of workers without training to zero; (ii) we assume that the wage of a worker without training is also the reservation wage for the trained workers, that is, their knowledge is useless outside the industry under consideration. After having obtained the wage offers, each employee accepts the highest offer.[12] Denote the number of trained workers

[11] Here "wages" should be interpreted broadly, including any type of non-monetary benefits such as pleasant working environments, fringe benefits and flexible working hours which involve costs for the employer. A priori we allow wages to differ even for individuals who have the same level of human capital or belong to the same firm.

[12] As a tie-breaking rule, we use the convention that the employee stays with his original firm if this firm offers the highest wages. Moreover, the turnover game has the structure of

in firm i at the end of period 2 as t_i. Recall that G is the total number of trained workers in period 1, which is the same as the total number of firms that train their workers. Hence $G = \sum_{i=1}^{n} t_i$. As firms can now have more than one trained worker, we need to define the cost function more generally as

$$c(t_i) = \frac{c}{\delta t_i + 1} \text{ for some } \delta > 0. \tag{6}$$

In period 3, Cournot competition with demand $x = \frac{I}{B}(a-p)$ takes place. Gross profits depend on marginal costs, as in (1). Using (6), gross profits are therefore functions $\widetilde{\pi}_i(t_1, ..., t_I)$ of the distribution of trained workers after the poaching game. As t_j can now be greater than 1, the distribution of workers across competitors is not necessarily uniform and the notation $\pi_i(t_i, G)$ is no longer well-defined, unless we apply the following conventions:

(i) If $G - t_i \leq I - 1$, $\pi_i(t_i, G)$ refers to the case that every competitor of firm i has at most one trained worker.

(ii) If $G - t_i > I - 1$ or equivalently if $t_i = 0$ and $G = I$, $\pi_i(t_i, G)$ refers to the case that one firm has two trained workers while all other competitors of firm i have one worker.

Table 1: **Game Structure**

Period 1:	Firms $i = 1, ..., I$ choose training levels g_i.
Period 2:	(i) Firms choose wage offers $w_{i,j}(g_1, ..., g_I)$.
	(ii) Workers choose between employers, thus determining the numbers t_i of trained workers.
Period 3:	Product market competition results in gross profits $\widetilde{\pi}_i(t_1, ..., t_I)$.

We summarize the game in Table 1. We distinguish between *net profits* and *gross profits*, according to whether wages for trained workers are deducted or not. We define the *long-term payoff* as the difference between

an auction with externalities where multiple auctioneers (the workers) auction themselves to multiple bidders (the firms).

net profits and training expenses. Finally, we define the *product market subgames* as the subgames starting in Period 3 and the *turnover subgames* as the subgames starting in Period 2. To simplify the notation further, we often neglect the index i in the profit variable and write $\pi(t_i, G)$.

3.2 Sufficient Conditions for Training – Overview

We first consider sufficient conditions for a training equilibrium $(g_1, ..., g_I) = (1, ..., 1)$. Necessary conditions are harder to establish, and they will be discussed in Appendix 3. We first sketch how we arrive at sufficient conditions. Later, we shall fill in the details.

For $t_i \in \{2, ..., I\}$, define

$$AP(t_i, I) \equiv \frac{\pi(t_i, I) - \pi(1, I)}{t_i - 1}. \quad (7)$$

Starting from a situation where all firms have one trained worker, $AP(t_i, I)$ is the *average productivity* of each of the $t_i - 1$ workers that a firm poaches in the turnover stage. From a firm's point of view, the positive productivity effect of poaching also consists of the negative effect imposed on the competitor: As (1) shows, poaching increases profit by reducing its costs and by increasing its competitors' costs. Similarly, define

$$MP(t_i, I) = \pi(t_i + 1, I) - \pi(t_i, I) \quad (8)$$

as the *marginal productivity* of poaching an additional worker for a firm that has t_i of the I workers in the market. We maintain the following assumptions.

Assumption 1

$$\max_{t_i \in \{2,...,I\}} AP(t_i, I) \leq MP(1, I); \quad (9)$$

$$\max_{t_i \in \{2,...,I-1\}} AP(t_i, I-1) \leq MP(0, I-1) \quad (10)$$

The assumption clearly holds if the marginal productivity of poaching is decreasing in t_i. It will be useful for the analysis of the turnover subgames and the proof of our following main result:

Theorem 2 *A training equilibrium exists if*

$$\theta(I) \equiv 2\pi(1, I) - \pi(2, I) - \pi(0, I-1) \geq T. \tag{11}$$

$$MP(0, I-1) \geq MP(1, I-1) \tag{12}$$

The proof will consist of the following steps.

1. Gross product market profits in a training equilibrium are $\pi(1, I)$.

2. Proposition 2 below: If (11) holds and I firms have trained their workers, there is an equilibrium of the ensuing turnover game where each firm retains its worker and pays $w^* = MP(1, I)$.

3. Propositon 3 below: If (12) holds and $I-1$ firms have trained their workers, there is an equilibrium of the ensuing turnover game where each of these firms retains its worker and obtains net profits $\pi(0, I-1)$.

4. The net training incentive, that is, the difference between net profits in the training equilibrium and net profits for a firm that deviates to "no training" is therefore given by $\theta(I) = \pi(1, I) - MP(1, I) - \pi(0, I-1)$, so that (11) implies the result.

We now fills in the gaps by proving Propositions 2 and 3.

3.3 The Turnover Equilibrium

We first consider the subgame where all firms have trained their workers

Proposition 2 *Suppose each firm has trained one worker in period 1.*
(a) Suppose

$$MP(0, I) \geq MP(1, I). \tag{13}$$

Then there is an equilibrium of the turnover game where the highest wage offer for each worker is $w^* = MP(1, I)$.[13] *In any equilibrium each firm employs exactly one trained worker.*

[13]The equilibrium is supported by wage offers $w_{ij} = w^*, i = 1, \ldots, I$ and $j = 1, \ldots, I$, or alternatively, by wage offers w^* to only two workers, i.e., $w_{ii} = w^*$, $w_{ii+1} = w^*$ for $i = 1, \ldots, I-1$ and $w_{I1} = w^*$, $w_{II} = w^*$ and zero wage offers in all other cases.

(b) Suppose that condition (13) does not hold. Then, in any subgame perfect equilibrium in pure strategies there is at least one firm without a trained worker. In equilibrium, this firm cannot have lower net profits than any firm with a trained worker.

Proof. See Appendix 1 ■

Because $\pi(0, I-1) > \pi(0, I)$, (11) implies (13). Thus, step 2 above follows from Proposition 2. To see the intuition of Proposition 2, note that w^* is the willingness of each firm to pay for a second worker. Condition (13) guarantees that, starting from an equal distribution of workers, the gains for a firm from attracting a worker ($MP(1, I)$) are (weakly) smaller than the losses if a competitor attracts one of its worker ($MP(0, I)$). Thus, each firm is willing to offer $w^* = MP(1, I)$, and there is no turnover. By (9), it is not a profitable deviation to attract further workers from the competitors: Their average productivity is below the wage, which is the marginal productivity of the second worker.[14]

To analyze deviation incentives, we consider the subgame where one firm does not invest into training (step 3 above).

Proposition 3 *Suppose that $I-1$ firms have trained their workers and (12) holds. Then, the resulting turnover game has an equilibrium where each worker receives a maximal wage offer of $w^* = MP(0, I-1)$ and $(I-1)$ firms employ exactly one worker. Accordingly, net profits for all firms are $\pi(0, I-1)$.*

Proof. See Appendix 1. ■

As (12) is an assumption of our main result, step 3 above follows. Compared to the case where all firms have trained their workers, trained workers

[14] Note that Part (b) of Proposition 2 is not a full description of the turnover game. For our analysis, we do not require such a full solution which amounts to a tedious case-by-case discussion. For instance, for the case that I is even, we calculated conditions for an equilibrium where half the firms have two workers each, but the others have none. Equilibrium wages are such that all firms have identical net profits.

are now more valuable as they are relatively scarce. As a result, wages are higher: $MP(0, I-1)$ is bounded below by $\pi(1, I) - \pi(0, I-1)$, which, in turn, is bounded below by $MP(1, I)$ when (11) holds. In other words, by training, firms increase the supply of trained workers and thereby reduce their wages.

3.4 Other Equilibria in Pure Strategies

We first show that there always is an equilibrium without training.

Proposition 4 *The equilibrium* $(g_1, \ldots, g_I) = (0, \ldots, 0)$ *always exists.*

Proof. See Appendix 1. ■

Intuitively, deviating from no training is unattractive, as the only firm with one trained worker faces the threat that the worker moves to a competitor. We next consider partial training equilibria.

Proposition 5 *Suppose that* $\hat{I} \in \{1, 2, ..., I-1\}$ *firms have trained a worker and*

$$MP\left(0, \hat{I}\right) \geq MP\left(1, \hat{I}\right); \tag{14}$$

$$\max_{t_i \in \left\{2, \ldots, \hat{I}\right\}} AP\left(t_i, \hat{I}\right) \leq MP\left(1, \hat{I}\right). \tag{15}$$

Then, no partial training equilibrium exists.[15]

By (14) and (15), a firm has at most one worker in the turnover game. Therefore, the net profits of a deviating firm are $\pi\left(0, \widehat{I}-1\right)$, whereas they are $\pi\left(0, \widehat{I}\right)$ before deviation. Thus, even without accounting for training costs, deviation from a partial training equilibrium by not training is always profitable.

[15] If condition (14) or (15) is violated, a partial training equilibrium still does not exist if an analogue of Condition ICW in Appendix 8.3 holds, with I replaced by $\widehat{I}$.

4 The Effects of Globalization on Training

4.1 Introduction

We now analyze the effects of labor and product market integration on training behavior. In Section 4.2 we show how *full integration* of both product and labor markets affects training behavior. In 4.3, we consider pure *labor market integration* (with separated product markets).

4.2 Full Integration

To analyze the effects of integrating both labor and product markets, we now compare the model of Section 3 for $I = I_1$ and $I = I_2$ with the model for $I = I_1 + I_2$.[16] Figure 2 depicts net training incentives $\theta(I)$ for $a = 10$, $B = 1$, $c = 1$.[17] For $\delta = 0.1$ (lower curve), there is no value of I for

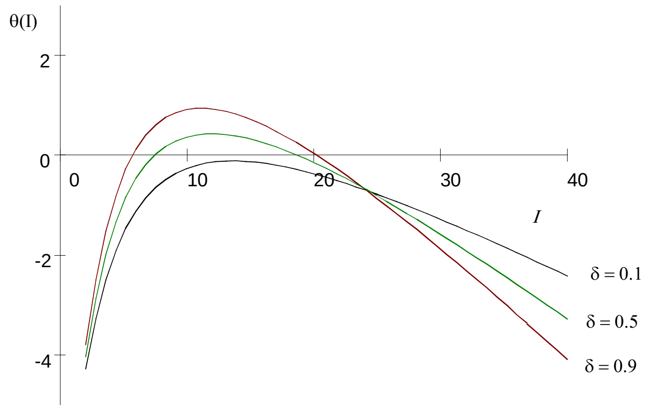

Figure 2: Net Training Incentives

[16]Note that we assume that the number of firms in both countries stays the same after integration. This is justified from a short-term perspective or if entry costs are sufficiently high. In future research, we will examine the long-term effects of globalization on training when there is free entry and exit.

[17]We have compiled the relevant profit formulas in Appendix 8.2.

which $\theta(I)$ is positive. As δ increases, there is an intermediate range of I-values for which $\theta(I)$ is positive. This region is greater for $\delta = 0.9$ than for $\delta = 0.5$. In all three cases, training incentives are first increasing, then decreasing in I. Partly, this reflects the intuition from the IWG: Increasing market size increases the returns to training, whereas the increasing number of competitors reduces the returns to training. In addition, however, there is an additional wage effect that is absent in the model with immobile workers. As we shall show in the next section, wages $w^* = \pi(2, I) - \pi(1, I)$ for trained workers are increasing in I, which tends to exacerbate the potential negative effects of integration on training incentives.

The patterns exposed in Figure 2 hold more generally: The net training incentives are typically hump-shaped. Therefore, as the next Proposition reveals, as the initial country size increases, we move through the different regimes as follows.

Proposition 6 *Suppose $I_1 = I_2 = I^A$. There exist I^*, I^{**}, I^{***}, I^{****} such that $0 \leq I^* \leq I^{**} \leq I^{***} \leq I^{****}$ and:*

(i) *For $I < I^*$: The no-training equilibrium prevails before and after integration.*

(ii) *For $I^* < I < I^{**}$: Integration induces training.*

(iii) *For $I^{**} < I < I^{***}$: The training equilibrium prevails before and after integration.*

(iv) *For $I^{***} < I < I^{****}$: Integration destroys training.*

(v) *For $I > I^{****}$: The no-training equilibrium prevails before and after integration.*

Note that some of these intervals may be degenerate.[18]

[18] Most obviously, for instance, if T is high, there will be no training equilibrium independent of I^A.

Figure 3 shows the possible effects of integration on training for symmetric countries, depending on the initial market size I^A. Therefore, integration has a positive effect on training if the markets are initially small and a negative effect if the markets are initially large. When $\theta(I_1) < T$ and $\theta(I_2) < T$, but $\theta(I_1 + I_2) > T$, integration induces training. Conversely, when $\theta(I_1) > T$ and $\theta(I_2) > T$, but $\theta(I_1 + I_2) < T$, integration destroys the training equilibrium, when none of the above intervals is degenerate.

4.3 Pure Labor Market Integration

We now sketch the effects of pure labor market integration without product market integration. We compare training incentives in the autarky models for $I_1 = I_2 \equiv I_A$ with those for the *integrated labor market* (ILM) game, defined as follows.

In stage 1, firms in both countries make training decisions as in the MWG. In stage 2, however, each firm makes wage offers to all trained workers in the two countries. In stage 3, product market competition takes place in each country as in the MWG. For $t_i \in \{1, ..., I_A\}, t_i^* \in \{1, ..., I_A\}$, define

$$AP(t, t_i^*, I_A) \equiv \frac{\pi(t_i + t_i^*, I_A + t_i^*) - \pi(1, I_A)}{t_i + t_i^* - 1} \tag{16}$$

This expression is the average productivity per poached worker if firm i has t_i workers trained in its own country and t_i^* workers trained abroad. In terms of their profit effects, foreign and home-country workers are not perfect substitutes although trained workers generate the same cost reduction irrespective of the country where they received training. While hiring either type has a positive effect on a firm's efficiency, hiring a home-country worker also reduces the efficiency of a direct competitor.

Proposition 7 *Suppose in the ILM game each firm has trained one worker in period (1). Suppose the following conditions hold:*

$$MP(0, I_A) \geq MP(1, I_A); \tag{17}$$

$$\max_{t_i, t_i^* \in \{1,\ldots,I_A\}} AP\left(t_i, t_i^*, I_A\right) \leq MP\left(1, I_A\right) \tag{18}$$

Then there is an equilibrium of the turnover game where the highest wage offer for each worker is $w^* = MP\left(1, I_A\right)$. *In any equilibrium, each firm employs exactly one worker.*

The proof is analogous to Proposition 2. The main difference is between (9) and the more restrictive condition (18): In the *ILM* model, each firm can also deviate by poaching abroad. However, poaching at home is more attractive because it raises rivals' costs. Thus a firm will only poach abroad if it already employs all home-country workers. As a consequence, the additional poaching opportunities with labor market integration are likely to be irrelevant.

Proposition 3 generalizes in an analogous fashion, with (13) replaced by $MP\left(0, I_A - 1\right) \geq MP\left(1, I_A - 1\right)$ and (10) replaced by

$$\max_{\substack{t_i \in \{1,\ldots,I_A\} \\ t_i^* \in \{1,\ldots,I_A\}}} AP\left(t_i, t_i^*, I_A - 1\right) \leq MP\left(0, I - 1\right) \tag{19}$$

Proposition 3 generalizes to the ILM model if we replace our maintained assumptions (9) and (10) with (18) and (19).

To sum up, after pure labor market integration, a training equilibrium exists under analogous condition as under autarky, except that our maintained assumptions (9) and (10) have to be sharpened. This suggests that the effects of full integration are essentially the effects of product market rather than labor market integration.

5 Welfare and Distributional Effects of Full Integration

5.1 Preliminaries

We now explore the welfare effects of full integration for symmetric countries ($I_1 = I_2 \equiv I_A$), demand function $X(p, I) = \frac{I}{B}(a - p)$, and costs $c(t_i) = \frac{c}{\delta\, t_i + 1}$

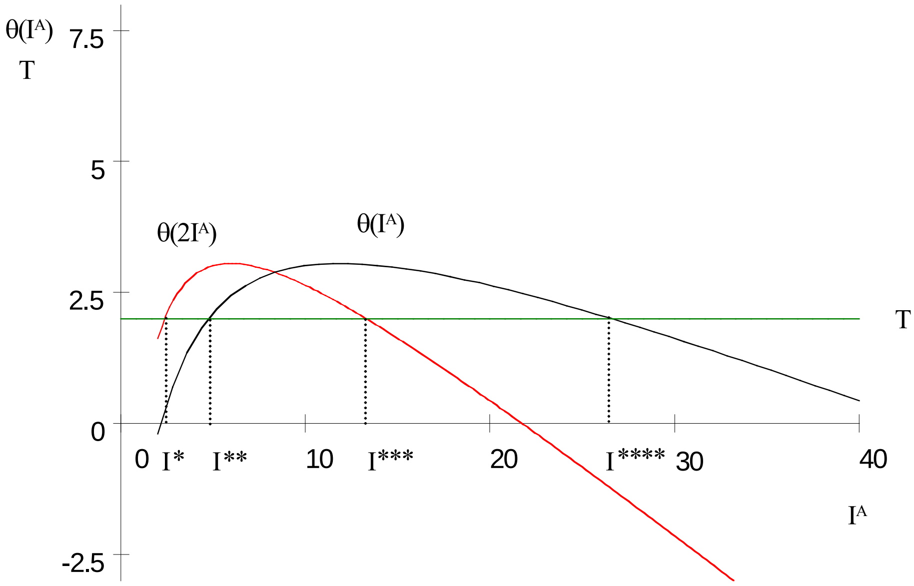

Figure 3: The Effects of Integration

for some $\delta > 0$.[19]

We define welfare W_I as the sum of consumer surplus, producer surplus and workers' rents. Denote prices in the training and no training equilibrium as $P_I(T)$ and $P_I(0)$, respectively. Welfare in the no-training equilibrium is

$$W_I^0 \equiv I\,\pi(0,0) + \int_{P_I(0)}^{a} X(p,I)dp = \frac{I\,(a-c)^2\,(I+2)}{B\,(I+1)^2}$$

As the wages of trained workers enter the producer surplus negatively, they cancel out. Thus, in the training equilibrium, welfare is

$$W_I^T = I\,\pi(1,I) + \int_{P_I(T)}^{a} X(p,I)dp - IT = \frac{I\left(a - \frac{c}{1+\delta}\right)^2 (2+I)}{B\,(I+1)^2} - IT.$$

In general, the welfare effects of integration can be decomposed in two parts. First, there is the standard effect of market integration for fixed levels

[19] The extension to heterogeneous countries is straightforward.

of training (i.e., the comparison of $2W_I$ and W_{2I}). Second, there is the effect of moving from a training equilibrium to a no-training equilibrium (or vice versa) for given levels of integration (i.e., the comparison of W_I^T and W_I^0).

Lemma 1 *Suppose (11) and (12) hold and hence the training equilibrium exists. Then* $W_I^T \geq W_I^0$ *provided*

$$\pi(2,I) - \pi(1,I) + \pi(0,I-1) + \frac{1}{I}\int_{P_I(T)}^{a} X(p,I)dp \geq \pi(0,0) + \frac{1}{I}\int_{P_I(0)}^{a} X(p,I)dp. \quad (20)$$

Proof. See Appendix 1. ■

As a price reduction increases the consumer surplus, a sufficient condition forcondition (20) to hold is therefore

$$\pi(2,I) - \pi(1,I) + \pi(0,I-1) \geq \pi(0,0).$$

After tedious calculations, this leads to

$$I^2\left[c\delta\left(1+2\delta^2+2\delta\right)\right] + I\left[3c\delta\left(1+2\delta\right) - 2a\delta\left(1+\delta^2+3\delta\right)\right] + 2\left[a-c-4c\delta\left(1+\delta\right) + a\delta\left(5+4\delta^2+8\delta\right)\right] \geq 0$$

The condition holds, for instance, for large I or for $\delta \approx 1$.

5.2 Integration with Unchanged Training Behavior

We now consider the welfare effects of integration when it does not affect training. For notational clarity we now include the firm number in the profit formula. Thus, $\pi^I(t_i, G)$ is the gross profit of a firm with t_i trained workers when the total number of firms and trained workers are I and G, respectively.

Proposition 8 *If integration does not affect training behavior, it*
(i) increases welfare;
(ii) raises wages of trained workers for sufficiently large values of I^A
(iii) reduces gross profits.

Proof. See Appendix 1. ■

Intuitively, without training effects, the only impact of integration on aggregate welfare is the price effect which benefits consumers and hurts producers, but is positive in the aggregate.

For distributional matters, however, it is also important that firms not only suffer from lower prices, but also from higher wages. This wage effect is consistent with the empirical findings of Feenstra and Hanson (2001) who provide evidence for an increase of skilled wages as a result of globalization. The effect results from an increase in labor demand brought about by integration: Increasing product market competition makes trained employees more valuable.

5.3 Integration Fosters Training

Now suppose integration induces training equilibria.

Proposition 9 *Suppose that, for $I = I^A$, no training equilibrium exists, but for $I = 2I^A$ it does. Suppose integration induces training. Then:*
(i) Prices fall.
(ii) If (20) holds for $I = 2I^A$, welfare increases.
(iii) Even if (20) does not hold, welfare only falls if firms switch to a Pareto-dominated training equilibrium as a result of integration.[20]

Proof. See Appendix 1. ■

As discussed in subsection 5.1, (20) holds if I^A is large. Thus, integration fosters welfare in this case. If integration induces training, both the competition effect of integration described in Proposition 8 and the effect of lower costs work towards lower prices.

[20] We refer to Pareto-dominance with respect to the set of firms here.

5.4 Integration Destroys Training

When integration destroys training, the welfare effects are ambiguous. Apart from the obvious fact that reductions in training expenses have a positive ceteris paribus effect on welfare, there are ambiguous price effects. The absence of training increases marginal costs, but competition reduces markups.

Proposition 10 *Suppose that a training equilibrium exists and is selected for $I = I^A$, but not for $I = 2I^A$.*

(i) Prices fall as a result of integration if and only if

$$a > A^* := \frac{c}{1+\delta}\big(1 + 2\delta(I^A + 1)\big).$$

(ii) If $a > A^*$, integration increases welfare.

Proof. See Appendix 1. ■

If $a > A^*$, the mark-up reduction resulting from integration dominates over the higher marginal costs because of the absence of training. As prices are lower and training costs are saved, welfare must increase. If $a < A^*$, however, integration may reduce welfare. Intuitively, the higher marginal costs after integration outweigh the lower mark-up and the savings in training expenses. Figure 5 illustrates this possibility for our standard parameter values $a = 10, c = 1, B = 1$ in the case $\delta = 0.9$: $\theta\left(I^A\right)$ and $\theta\left(2I^A\right)$ are the net training incentives before and after integration, respectively. $\Delta W\left(I^A\right)$ denotes the welfare loss per worker that is not trained due to integration (gross of training costs), that is $\Delta W\left(I^A\right) = \left(2\left(W^T_{I^A} + I^A T\right) - W^0_{2I^A}\right)/2I^A$. For $I^A_{\min} < I^A < I^A_{\max}$, integration destroys training for all $T \in \left[\theta\left(2I^A\right), \theta\left(I^A\right)\right]$. At the same time, for those I^A and T that are in the shaded area, we have $T < \theta\left(I^A\right) < \Delta W\left(I^A\right)$, such that the welfare losses outweigh the savings in training costs. Therefore, for these parameters, whenever integration destroys training, this reduces welfare.

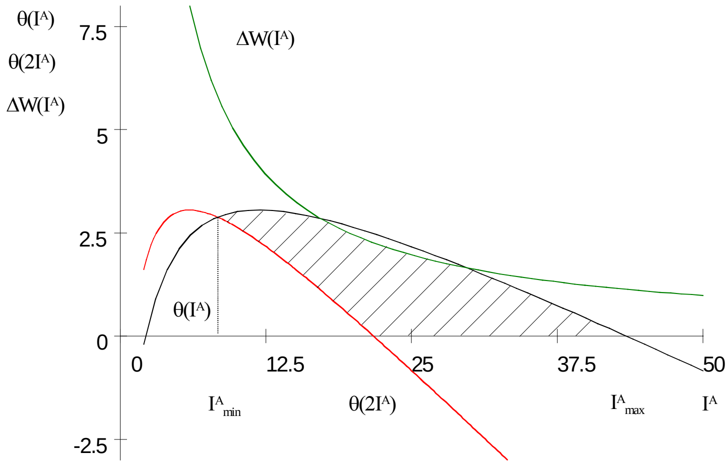

Figure 4: Welfare and the Destruction of Training Equilibria

6 Different Training Systems

6.1 The Model

Until now we have considered the impact of globalization when firms in both countries have access to the same training technologies. Countries differ, however, in this respect (see, e.g., Ryan 2001). We therefore ask how global competition between countries with different training systems affects training incentives, focussing on apprenticeship systems of the German type. The existing literature largely concludes that firms are willing to pay a share of the training costs, although the apprentices mainly acquire general skills.[21]

The *Systems Competition Game (SCG)* is described as follows. We suppose country 1 has an apprenticeship system where $I_1 \geq 2$ firms train their workers as in the *MWG*, whereas in country 2 firms use workers whose training is publicly funded, so that there are I_2 firms with marginal costs of $c - \varepsilon$,

[21]See Franz and Soskice 1995, Oulton and Steedman 1994, Harhoff and Kane 1997, Acemoglu and Pischke 1998, Euwals and Winkelmann 2001, Büchel 2002, Clark and Fahr 2001.

$\varepsilon \geq 0$.[22] The product market is integrated. Finally, we assume that labor is mobile only within national borders. Firms from countries 1 and 2 compete in a global market place. Profits of firms in country 1 are described by the notation $\tilde{\pi}_i(t_i, G)$ with the same conventions as in Section 3.1. $\tilde{\pi}_i(t_i, G)$ is the profit of a firm i if it has t_i trained workers, and $G - t_i$ trained workers are employed by competitors; similarly, we introduce for $\widetilde{AP}(t, I)$ and $\widetilde{MP}(t, I)$ and use these quantities to modify Assumption 1.[23] Finally, we shall compare the SCG with the reference case of autarky in country 1, for which a training equilibrium exists if (11) holds with $I = I_1$.

Proposition 11 *A training equilibrium in the SCG exists if the following conditions hold:*

$$2\tilde{\pi}(1, I_1) - \tilde{\pi}(2, I_1) - \tilde{\pi}(0, I_1 - 1) > T;$$

$$\widetilde{MP}(0, I - 1) \geq \widetilde{MP}(1, I - 1)$$

The proof is analogous to Proposition 2.

6.2 Example

We now present some simple illustrations for the effects of international competition between training systems.[24] We distinguish two cases. In the first case, country 1 faces competition by I_2 firms in country 2 that each have one trained worker, that is, $c_i = \frac{1}{\delta+1}$ or equivalently, $\varepsilon = c\frac{\delta}{\delta+1}$. In the second case, country 2 has only low-skilled workers, that is, $\varepsilon = 0$. Parameter values are $a = 10$, $b = 1$, $c = 1$, $\delta = 0.9$.

[22]Hence, ε is the net cost effect which incorporates the productivity effect of trained workers and associated wage costs. When firms have to pay taxes to finance public vocational schools, such tax effects would have to be included as well.

[23]Obviously, $\widetilde{\pi}_i(t_i G)$ also depends on I_2; but we suppress this variable.

[24]In Appendix 3, we list all relevant payoff functions.

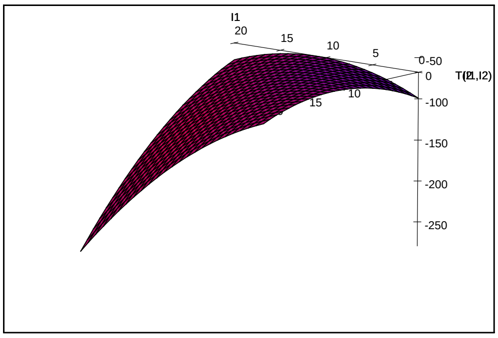

Figure 5: Systems Competition, $\delta = 0.9$

Figure 5 shows training incentives as functions of I_1 and I_2 for publicly funded training. Similarly, Figure 6 gives training incentives for competition from low-skill countries. In the latter case, the non-monotonicity familiar

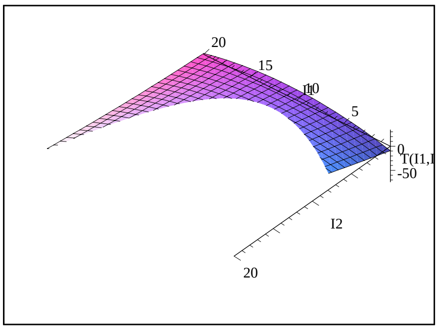

Figure 6: Low-Skill Competition, $\delta = 0.9$

from our earlier models reoccurs. For sufficiently small I_2, product market integration may increase incentives to train. For larger values of I_2, integration unambiguously lowers benefits from training. However, Figure 5 suggests that the positive effects of integration for small values of I_2 may disappear altogether. Hence, systems competition may be an even larger threat to apprenticeship systems than the integration of product markets where all firms are subject to the same training technologies.

Euwals and Winkelmann (2001) explain the decline in the number of apprentices over the last decade in Germany with demographic and compositional factors. Our theoretical analysis suggests that globalization might have accelerated the decline of the apprenticeship system. With such forces undermining the sustainability of the system, education policy faces the difficult decision of whether or not to give incentives to stabilize the system.

7 Extensions and Conclusions

Our paper makes the following main points: First, the effects of product market integration on training incentives are positive when the initial market sizes are small and negative when they are large. Second, when integration destroys training, the net effect on welfare may be negative. Third, if trained labor is homogeneous, labor market integration has essentially no effects on training. Finally, systems competition might undermine training systems.

As yet, our approach uses several simplifying assumptions. For instance, we have treated training as a zero-one decision. It is perceivable that a continuous treatment of training levels would lead to qualitative changes of the results.

Another simplification concerns the exogeneity of firm entry decisions. In our approach, integration does not affect the total number of firms in the market: The number of firms in the integrated market is simply the sum of firms in each market. Alternatively, one could consider a setting where the firm number is endogenous and firms might enter or exit as integration takes place. Vives (2003) considers this possibility for a situation resembling our case of immobile workers. In future research, we shall explore the robustness of our conclusions with respect to free entry and exit.

8 Appendices

8.1 Appendix 1: Proofs

8.1.1 Proof of Proposition 2

First, we show that, if (13) and (9) hold, there is indeed an equilibrium such that each worker is offered w^* by each firm, and therefore each firm employs exactly one worker at the end of the turnover game. By (13), the gross profit reduction from having no trained worker instead of one outweighs the reduction in wage payments w^*, so that reducing the wage offer is not a profitable deviation. Conversely, to attract $t_i - 1$ more trained workers, a firm has to offer them wages slightly above w^*, leading to gross profits $\pi_i(t_i, I)$ and wages of approximately $\pi_i(2, I) - \pi_i(1, I)$ per worker. The relevant non-deviation condition is thus

$$\pi_i(t_i, I) - \pi_i(1, I) \leq (t_i - 1)[\pi_i(2, I) - \pi_i(1, I)] \text{ for all } t_i \geq 2. \qquad (21)$$

Clearly, (9) and (21) are equivalent.
Next, suppose in equilibrium one firm (say firm 1) has at least two workers, whereas some other firms have none. By conditions (13) and (9), firm 1 is willing to pay at most $\pi_i(1, I) - \pi_i(0, I)$ on average for each of its workers. As the firms from which firm 1 has poached the workers would also be willing to pay that quantity to retain their workers, the amount does not suffice to poach the workers.
(b) Suppose that condition (13) does not hold, that is, $MP(1, I) > MP(0, I)$. First, a symmetric training equilibrium requires that wages are at most $MP(0, I)$; otherwise firms could profitably deviate by reducing the wage so that they do not employ a worker. As $MP(1, I) > MP(0, I)$, with such a proposed equilibrium wage, firms could profitably deviate by offering a slightly higher wage, so as to employ a second worker. Thus any subgame equilibrium must involve an asymmetric worker distribution. If firm i has smaller net profits, it can deviate by offering slightly higher wages to the

workers of firm j, so that these workers go to firm i and it approximately earns the higher net profits of firm j.[25]

8.1.2 Proof of Proposition 3

If each firm offers w^*, all firms receive net profits $\pi(0, I-1)$. First, consider deviation incentives for firms that employ a trained worker in equilibrium, that is, firms with gross profits $\pi(1, I-1)$ that pay wages $MP(1, I-1)$. Downward deviations (below w^*) for such firms would not be profitable. They would not have to pay wages, but gross profits would drop to $\pi(0, I-1)$. By increasing wages slightly above w^*, a firm could obtain additional workers. Gross profits from hiring $t_i - 1$ workers would be $\pi(t_i, I-1)$ rather than $\pi(1, I-1)$. Subtracting wage payments, the net gain from deviation is thus approximately

$$\pi(t_i, I-1) - \pi(1, I-1) - (t_i - 1)(\pi(1, I-1) - \pi(0, I-1)) < 0.$$

By (10), this expression is non-positive. Next, consider the incentives of the firm without a worker to increase its wage offer slightly. This would increase gross profits by $\pi(1, I-1) - \pi(0, I-1)$, but increase wages by approximately the same amount. More generally, increasing wage offers to any number $(t_i - 1)$ of workers is not profitable by (10).

8.1.3 Proof of Proposition 4

Firm's profits in equilibrium are given by $\pi(0,0)$. When one firm deviates to $g_i = 1$, the trained worker will end up at the deviating firm in the turnover game according to our tie-breaking rule. As the wage for the trained worker will be bid up to $\pi(1,1) - \pi(0,1)$, all firms will end up with a net payoff of $\pi(0,1)$. Hence, the deviating firm would have a long-term payoff of $\pi(0,1) - T$, hence the deviation is not profitable.

[25] Note that no other firm offers the same wages in the candidate equilibrium since otherwise workers would not stay at firm j.

8.1.4 Proof of Proposition 6

First note that

$$\theta\left(I\right)=\frac{I}{\left(I+1\right)^{2}}\left(\alpha I^{2}+\beta I+\gamma\right)\text{ for constants }\alpha,\beta,\gamma\in\Re \tag{22}$$

Even though, we have defined $\theta\left(I\right)$ only on $\{2,3,...\}$, we can thus extend it to $[0,\infty]$.

Lemma 2 *$\theta\left(I\right)$ has the following properties.*
(i) $\theta\left(0\right)=0$
(ii) $\lim_{I\rightarrow\infty}\theta\left(I\right)=-\infty$
(iii) $\theta\left(I\right)$ crosses the I-axis at most twice.

Proof. (i) is immediate
(ii) follows because it can be shown that $\alpha<0$.
(iii) $\theta'\left(I\right)=\frac{\gamma+2\beta I-\gamma I+3\alpha I^{2}+\alpha I^{3}}{(2I+I^{2}+1)(I+1)}$. It can be shown that $\gamma<0$. Thus $\theta'\left(0\right)<0$. As the numerator of $\theta'\left(I\right)$ has at most three zeroes, (ii) implies that it has at most two zeroes on $\left[0,\infty\right]$. ■

The lemma immediately implies Proposition 6.

8.1.5 Proof of Lemma 1

Condition (11) can be rewritten as:

$$\pi(1,I)-T\geq\pi(2,I)-\pi(1,I)+\pi(0,I-1)$$

Thus (2) implies

$$\pi(1,I)+\frac{1}{I}\int_{P_{I}(T)}^{a}X(p,I)dp-T>\pi(0,0)+\frac{1}{I}\int_{P_{I}(0)}^{a}X(p,I)dp.$$

8.1.6 Proof of Proposition 8

(i) If there is a training equilibrium before and after integration welfare increases if, and only if, $P_{2K}(T) < P_K(T)$, as $W_{2K}^T > W_K^T$ reduces to a simple comparison of the sum of gross producer and consumer surplus before and after integration. From (2), $P_{2K}(T) < P_K(T)$ is obvious. The proof for the equilibrium without training is analogous.
(ii) Calculating wages $w^*(I)$ as a function of I yields

$$\begin{aligned} w^*(I) &= MP(1,I) = \pi^I(2,I) - \pi^I(1,I) \\ &= \frac{I}{B(I+1)^2}\left[\left(a + Ic\frac{\delta}{(2\delta+1)(\delta+1)} - c\frac{1-\delta}{\delta+1}\right)^2 - \left(a - \frac{c}{\delta+1}\right)^2\right]. \end{aligned}$$

For sufficiently large values of I, $\partial w^*/\partial I > 0$. Therefore $w^*\left(I^A\right) < w^*\left(2I^A\right)$ if I^A is sufficiently large.
(iii) follows immediately from

$$\frac{\partial \pi^I(1,I)}{\partial I} = \left(a - \frac{c}{\delta+1}\right)^2 \frac{1-I}{B(I+1)^3} < 0$$

8.1.7 Proof of Proposition 9

(i) $P_{2K}(T) < P_K(0)$ as $P_{2K}(T) < P_K(T)$ and $P_K(T) < P_K(0)$.
(ii) Integration increases welfare, if and only if,

$$2K\pi^{2K}(1,2K) + \int_{p_{2K}(T)}^{a} X(p,2K)dp - 2KT > 2K\pi^K(0,0) + \int_{p_K(0)}^{a} X(p,2K)dp.$$

Inserting $I = 2K$ in Condition (11) with $I = 2K$,

$$\pi^{2K}(1,2K) - T \geq \pi^{2K}(2,2K) - \pi^{2K}(1,2K) + \pi^{2K}(0,2K-1).$$

Using (20) with $I = 2K$, this implies

$$\pi^{2K}(1,2K) - T \geq \pi^{2K}(0,0).$$

Welfare therefore increases if

$$\int_{p_{2K}(T)}^{a} X(p,2K)dp > \int_{p_{2K}(0)}^{a} X(p,2K)dp.$$

This follows from $p_{2K}(T) < p_{2K}(0)$.
(iii) Follows immediately from (i).

8.1.8 Proof of Proposition 10

(i) By (2),

$$p_K(T) = \frac{a}{K+1} + \frac{Kc}{(K+1)(\delta+1)}$$

and

$$p_{2K}(0) = \frac{a}{2K+1} + \frac{2Kc}{2K+1}$$

Simple rearrangements show that $p_{2K}(0) < p_K(T)$, if and only if, $a < A^*$.

$$a > A^* \equiv \frac{c}{1+\delta}\big(1+2\delta(K+1)\big)$$

(ii) follows immediately from (i) since integration reduces prices and saves training costs.

8.2 Appendix 2: Gross Payoffs for the MWG

In Appendix 2, we compile the formulas we use for the numerical analysis:

$$\begin{aligned}
\pi_i(0,I) &= \frac{I}{B(I+1)^2}\left(a - Ic\frac{\delta}{\delta+1} + c\left(-\frac{2}{\delta+1}+\frac{1}{2\delta+1}\right)\right)^2; \\
\pi_i(1,I) &= \frac{I}{B(I+1)^2}\left(a - \frac{c}{\delta+1}\right)^2; \\
\pi_i(2,I) &= \frac{I}{B(I+1)^2}\left(a + Ic\left(\frac{1}{\delta+1}-\frac{1}{2\delta+1}\right) + c\frac{\delta-1}{\delta+1}\right)^2; \\
\pi_i(0,I-1) &= \frac{I}{B(I+1)^2}\left(a - Ic\frac{\delta}{\delta+1} - \frac{c}{\delta+1}\right)^2; \\
\pi_i(1,I-1) &= \frac{I}{B(I+1)^2}\left(a + c\left(\frac{\delta-1}{\delta+1}\right)\right)^2; \\
\pi_i(2,I-1) &= \frac{I}{B(I+1)^2}\left(a + Ic\left(\frac{1}{\delta+1}-\frac{1}{2\delta+1}\right) + c\frac{2\delta-1}{\delta+1}\right)^2;
\end{aligned}$$

8.3 Appendix 3: Necessary Conditions for a Training Equilibrium

First, we show that, if (11) is violated, but the "no-turnover" condition (13) holds, then the training equilibrium cannot exist. Second, if (13) is also violated, the training equilibrium cannot exist if we impose an additional plausible condition.

Proposition 12 *Suppose condition (11) does not hold, whereas (13) does. Then there is no training equilibrium.*

Proof. By Proposition 2 and condition (13), if $g_i = 1$ for all $i \in \{1, ..., I\}$, there is no turnover in the second stage, and each firm obtains a long-term payoff of $2\pi(1,I) - \pi(2,I) - T$. Deviating to "no training", a firm would obtain $\pi(0,I-1)$ by Lemma 3. If condition (11) is violated, the deviation incentive is therefore positive. ■

Next, we consider the case that (13) does not hold. By part (b) of Proposition 2, when all firms have trained a worker, each firm's net payoff will be bounded above by the gross payoff of a firm with no trained worker that faces I trained workers employed by competitors. If a firm deviates to no training, it will employ no worker in the equilibrium of period 2. Therefore, it will have a net payoff that is the product market payoff of a firm that faces $I-1$ trained workers. The following condition therefore appears to be plausible.

Condition ICW *(Increasing Competition for Workers): If (13) is violated, a firm earns lower net profits in the training game where each of the I firms trains than when it deviates to "No Training" while all other firms train.*

Therefore, if (ICW) holds, even if training costs were zero, firms would prefer not to train. Thus, clearly, there can be no training equilibrium.

However, there is a snag in the argument. We have not yet said anything about the distribution of workers in the subgames we are comparing. The argument is sound if, in the subgame with I workers, $(I-1)$ workers are distributed exactly as in the subgame with $(I-1)$ workers, and the Ith worker is added to one firm. However, if, in the equilibrium of the game with I trained workers, there is at least one competitor of firm i that has a smaller number of trained workers than in the game with $I-1$ trained workers, firm i's payoff *may* be higher in the game with more trained workers, and training could be an equilibrium in principle.[26] However, such an equilibrium would require that the marginal productivity of a worker changes massively from I to $I-1$. We have not found an example where this occurs.

[26]For instance, by (1), if a firm without trained workers has two competitors, it has strictly higher profits when each competitor has one trained worker than when one competitor has one trained worker and the other has two. However, one can show that if three employees work in one other firm, payoffs are higher than when each of the two competitors has one trained worker if $\delta > \frac{1}{3}$.

8.4 Appendix 4: The Systems Competition Game

This Appendix contains the Payoffs that were used in the calculations in Section 6.

$$
\begin{aligned}
\tilde{\pi}_i\left(1, I_1\right) &= \left(\alpha + \frac{\delta c}{\delta+1} + I_2 \frac{\delta c}{\delta+1} - I_2 \varepsilon\right)^2, \\
\tilde{\pi}_i\left(2, I_1\right) &= \left(\alpha + I_1 c \left(\frac{1}{\delta+1} - \frac{1}{2\delta+1}\right) + 2c \frac{\delta}{\delta+1} + I_2 c \frac{2\delta}{2\delta+1} - I_2 \varepsilon\right)^2, \\
\tilde{\pi}_i\left(0, I_1 - 1\right) &= \left(\alpha - I_1 c \frac{\delta}{\delta+1} + c \frac{\delta}{\delta+1} - I_2 \varepsilon\right)^2.
\end{aligned}
$$

9 References

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