Product Markets and Industry-Specific Training

Hans Gersbach*
ETH Zurich and CEPR
Armin Schmutzler**
University of Zurich, CEPR and ENCORE

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ABSTRACT: We develop a product market theory that explains why firms provide their workers with skills that are not only useful in the firm itself, but also for potential future employers. In our model, firms first decide whether to invest in industry-specific training, then make wage offers for each others' trained employees and finally engage in imperfect product market competition. Equilibria with and without training, and multiple equilibria can emerge. If competition is sufficiently soft, firms will invest in training if others do the same. Thereby, they avoid having to pay high wages for trained workers. Furthermore, we draw welfare conclusions from the analysis, and we use it to explain cross-country differences in training.

Keywords: industry-specific training, human capital, oligopoly, turnover.

JEL: D42, L22, L43, L92.

Affiliations: *Hans Gersbach, CER-ETH, ETH Zurich, Zürichbergstrasse 18, 8032 Zurich, Switzerland, hgersbach@ethz.ch.
**Armin Schmutzler, Socioeconomic Institute, University of Zurich, Blümlisalpstr. 10, 8006 Zurich, Switzerland, armin.schmutzler@soi.uzh.ch.

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1 Introduction

Academic economists have been interested in worker training for a long time. The earlier literature (Pigou 1912, Rosenstein-Rodan 1943) stressed that firms may lack incentives to provide efficient levels of worker training. In his seminal work, Becker (1964) drew a crucial distinction between general and firm-specific skills. General skills are defined as those which are useful outside the firm that provides the training. In contrast, firm-specific skills are valuable only in the current employment relationship. In a competitive labor market where workers are paid according to their marginal product, firms would be willing to share some of the costs of firm-specific training investments, but they will never pay for general training.[1] However, the Beckerian prediction is at odds with the evidence.[2] Firms often bear a significant fraction of the costs of general training.[3] As will be discussed in detail in Section 5.2, economists have made great progress in understanding why Becker's theory fails and why firms pay for training.

This paper deals with a case that is intermediate between specific and fully general training: *Industry-specific training* provides workers with skills that are valuable outside the firm, but not outside the industry. In this case, training incentives would appear to be lower than for general training. Not only will the trained worker be of no value for the original employer; in addition, he will strengthen the competitor. Nevertheless, we shall argue that there is an explanation for firms' investments in industry-specific training.

To fix ideas, consider two firms that strategically interact over three

[1] This does not necessarily imply that the provision of general worker training is subject to market failure. As long as workers can pay for training, either directly out of their own pocket or by accepting wages below marginal products, efficient investment levels would obtain.

[2] See Acemoglu and Pischke (1998,1999), Franz and Soskice (1995), Katz und Ziderman (1990), OECD (1999).

[3] Several empirical studies show that a significant part of the training is not firm-specific (Baily and Gersbach 1995, Blundell et al. 1996, Goux and Maurin 1997, Loewenstein and Spletzer 1998, Regner 1995, 1997 and Vilhuber 1997, 1998).

stages. In a first stage (training stage), both firms decide how many workers to train. In a second stage (wage-bidding stage), firms compete through wage offers for the trained workers. Workers accept the better offer. Finally, in the product market stage, firms engage in oligopolistic product market competition. Our main result is that there often is a symmetric equilibrium with positive training levels. The key intuition is that, when skills are specific to an imperfectly competitive industry, firms can influence wages by training. With more trained workers, wages fall. Therefore, firms may have an incentive to provide such industry-specific training. However, the argument needs to be qualified. Because other firms also benefit from lower wages, training effectively provides a positive externality. Thus, firms will engage in training only when competition is not too intense.

In the remainder of the paper, we develop the intuitive argument in a simple game-theoretic setting. We establish conditions for positive training levels, and we provide several examples. For instance, we show that training can emerge in equilibrium when firms compete in prices in a differentiated-goods market. Finally, we draw welfare and policy conclusions from our analysis. We also use the analysis to explain cross-country differences in training.

The paper is organized as follows: In the next section, we use a simple example to illustrate the equilibrium without training. Section 3 introduces the model. Section 4 explores how competition affects the level of training investments. In Section 5, we compare our explanation for training to well-known alternatives. In Section 6 we discuss some policy implications. Section 7 concludes.

2 An Illustrative Example

We present a simple and highly stylized numerical example that highlights our main idea.

2.1 The Set-Up

There are two firms, $i = 1, 2$. A firm can either train one worker or none. Training costs are $I > 0$. We distinguish between net product market profits and gross product market profits, depending on whether training costs are subtracted or not.

For each combination of trained workers, we assume that there is a unique product market equilibrium with resulting gross product market profits $\pi^i(n^i, n^j)$ where $n^i(n^j)$ is the number of trained workers firm i (j) employs. We consider the following scenarios:

- If neither firm has trained, the market is shared at 0.5 units of gross profits each, that is, $\pi(0,0) = 0.5$.
- If only one firm trains, its gross profits are $\pi(1,0) = 0.95$; those of the competitor are $\pi(0,1) = 0.25$.
- If both firms have one trained worker, gross profits are $\pi(1,1) = 0.8$.
- If one firm employs both workers, gross profits are given by $\pi(2,0) = 1$ and $\pi(0,2) = 0.2$.

The specific numerical values have no significance for the analysis below. Even though we shall use these values for gross profits in this section, the essence of the argument in our paper will rely only on several qualitative properties. For instance, it is important that firm i's gross profits are increasing in the number of trained workers it employs, and decreasing in the number of trained workers of the competitor.

As a tie-breaking rule we assume that, if both firms offer the same wage, the worker stays with the firm where it was trained.

2.2 Wage Setting

Next, we consider wage setting for given training decisions of firms. Intuitively, bidding in the labor market entails wages equal to the minimum of the two firms' marginal valuations for a worker.[4]

If only one worker has been trained, the firm that employs him, say firm 1, has profits 0.95; if he works for the competitor, the gross profit falls to 0.25. Hence, both firms have a marginal valuation of 0.7 for the worker, so that the wage is $w^1 \equiv 0.7$.

Suppose both firms have trained one worker. If both firms employ one trained worker, their gross profits are 0.8; if instead one firm employed both workers, the competitor's profits would drop to 0.2. Thus, the marginal valuation for having one of the two trained workers (rather than none) is $\pi(1,1) - \pi(0,2) = 0.6$. Hiring a second worker would increase profits from 0.8 to 1, so that the marginal valuation for a second worker is only $\pi(2,0) - \pi(1,1) = 0.2$: This property of Decreasing Returns to Attracting Workers ($\pi(2,0) - \pi(1,1) < \pi(1,1) - \pi(0,2)$) will also play an important role in the general analysis.

We denote the equilibrium wage offered by both firms to each of two trained workers as w^2. We obtain $w^2 = 0.2 = 1 - 0.8$, and both trained workers will stay with their original firm. No firm can benefit from attracting a second trained worker.[5] Importantly, training therefore not only affects gross profits, but also wages. When more workers are trained, the wage level is lower ($w^2 < w^1$). This is the wage reduction effect, which will be the final important ingredient in the general analysis.

[4] The argument will be spelt out more carefully in Section 3.2.1.

[5] For an equilibrium with $w^2 = 0.2$ to arise, both firms offer this wage to both trained workers.

2.3 Training Decisions

With wages determined in this fashion, training decisions can be reduced to the simple matrix given in Table 1; where T corresponds to the case that the firm trains its workers and NT to the case that it does not.

Table 1: An Example

	T	NT
T	$0.8 - w^2 - I, 0.8 - w^2 - I$	$0.95 - w^1 - I, 0.25$
NT	$0.25, 0.95 - w^1 - I$	$0.5, 0.5$

For $I \leq 0.35$, a training equilibrium exists. The intuition is straightforward: Suppose one firm trains. Training by the other firm increases the supply of trained workers and lowers their wages from 0.8 to 0.2, as marginal profits from hiring more trained workers decline and the bidding game becomes less fierce. As wages drop sufficiently below the value of a trained worker for a firm, training by both firms is an equilibrium as long as $I \leq 0.35$.

For all $I \geq 0$ there also exists an equilibrium in which neither firm provides training. However, if $I < 0.1$, overall payoffs of each firm in the training equilibrium $(0.6 - I)$ are higher than in the no-training equilibrium, where they are 0.5.

3 The Model

3.1 Set-up

We now provide a model in which the qualitative properties of the numerical example can be derived from plausible general assumptions about product market competition.

There are two firms, indexed by i or j. In period 1, firms $i = 1, 2$ simultaneously choose their human capital investment levels $g^i \in \{0, 1, 2, ...\}$. g^i

can be interpreted as the number of employees of firm i receiving training. Training a worker costs $I > 0$ for a firm. At the beginning of period 2, firms simultaneously make individual wage offers for each of its own workers and for each of the competitor's workers.[6] We allow wages to differ even for individuals who have the same level of human capital or belong to the same firm.[7] We normalize wages of non-trained workers to zero. To capture the notion that human capital is industry-specific, that is, useless outside the industry, we assume that the wage of the non-trained worker is also the reservation wage for the trained workers.

After having obtained the wage offers, each employee accepts the higher offer. Denote the number of trained workers in firm i at the end of period 2 as n^i. We assume that employing trained workers is beneficial for the present employer because it helps to reduce marginal production costs.[8] This is reflected in our modeling of product market competition in period 3 as follows.

Assumption 1: *For each combination* (n^i, n^j) *of trained workers, there exists a unique product market equilibrium with resulting gross product market profit* $\pi^i(n^i, n^j) = \pi(n^i, n^j)$ *for firm* i*. For firms* $i = 1, 2$, $\pi^i(n^i, n^j)$ *is weakly increasing in* n^i *and weakly decreasing in* n^j*.*

Intuitively, the higher the number of trained workers in a firm, the lower its marginal costs and thus the higher the gross market profit. The higher the number of trained workers in the competitor's firm, the lower the competitor's marginal costs and thus the lower own gross profits.

Assumption 1 contains several implicit statements about the training technology and product market competition. The assumption that π de-

[6] 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.

[7] Denoting firm i's trained workers as $i_1, ..., i_m, ..., i_{g^i}$, wage offers have the form $w_{i,i_m}(g^i, g^j)$ for each of their own workers and $w_{i,j_m}(g^i, g^j)$ for each of the competitor j's workers $(j \neq i)$.

[8] Alternatively, one could assume that training leads to higher demand by improving product quality.

pends only on n^i and n^j, not on g^i and g^j, has two immediate implications. First, if an employee leaves the firm, the original employer loses all the benefits generated by the human capital investment - the employee leaves no traces once he has left the firm. Second, trained workers are perfect substitutes, no matter where they have been trained.[9] We shall show later on that training can nevertheless arise in equilibrium, in spite of this assumption. Finally, note that firms are symmetric in the sense that the profit function π depends on i only through the number of trained workers, not through the identity of the firm.[10]

With these properties of the training technology, Assumption 1 essentially only requires that (i) there is a unique product market equilibrium for arbitrary marginal cost vectors; (ii) firms with lower marginal costs have (weakly) higher gross profits, and (iii) higher marginal costs of the competitor increase own profits. (i)-(iii) are standard properties of static oligopoly models.

For technical reasons, it is often convenient to assume $\pi^i(n^i, n^j)$ is defined for arbitrary positive numbers $n^i \in \mathbb{R}^+$, not just for integers $n^i \in \mathbb{N}$. In addition, we shall suppose that π is differentiable. We use the following terminology:

- *Net product market profits*: $\pi(n^i, n^j)$ – *total wage payments.*
- *Long-term payoff*:

  $$\Pi\left(g^i, g^j\right) \equiv \pi\left(n^i\left(g^i, g^j\right), n^j\left(g^i, g^j\right)\right) - \textit{total wage payments} - g^i \cdot I,$$

  where $n^i(g^i, g^j)$ denotes the equilibrium number of workers in the subgame (g^i, g^j).[11]

The game structure is summarized in the Table 1.

[9] This assumption differs from the training literature which argues that one's own workers and competitors' workers are imperfect substitutes, because the ability of the own

Table 2: **Game Structure**

Period 1:	Firms $i = 1, 2$ choose training levels g^i.
Period 2:	(i) Firms choose wage offers.
	(ii) Workers choose between employers, thus determining the numbers n^i of trained workers.
Period 3:	Product market competition results in gross profits $\pi(n^i, n^j)$.

We can treat this game as a two-period game as follows: If the choices of the first two periods have led to a vector (n^i, n^j) of trained workers, we simply assume that gross product market profits correspond to the equilibrium payoffs of the product market game, $\pi(n^i, n^j)$.

We impose the following assumption on product market competition.

Assumption 2: $\pi(n, n)$ is weakly increasing in n.

Thus, gross profits increase (weakly) if, starting from an even distribution of workers, both firms increase the number of workers by the same amount. Assumption 2 holds in many duopoly models, because simultaneous symmetric cost reductions typically increase both firms' profits. Assumptions 1 and 2 will be satisfied in all examples that will be discussed below.

Finally, let $G = g^i + g^j = n^i + n^j$ denote the total number of trained workers. Then, to denote the value of an additional trained worker for a firm that has n^i out of a total of G workers, we write

$$v\left(n^i, G\right) = \pi\left(n^i + 1, G - n^i - 1\right) - \pi\left(n^i, G - n^i\right). \tag{1}$$

The size of $v(n^i, G)$ reflects aspects of technology and product market competition. Technology determines how large the cost reduction is that arises

worker is better known.

[10] In other words, there are no exogenous efficiency differences.

[11] The subgame $\left(g^i, g^j\right)$ is the two-period game that ensues after firms have chosen g^i and g^j in the first period. The notation $n^i\left(g^i, g^j\right)$ requires that a unique subgame equilibrium exists or that the resulting distributions of trained workers are independent of the equilibrium.

from having an additional trained worker. Product market competition determines how this cost reduction and the corresponding cost increase for the competitor translate into higher profits for the firm.

Note that, in our model, firms compete in the labor market for trained workers by offering wages, i.e., there is duopsonistic price competition in the labor market. This type of competition is kept constant throughout the paper, and we vary the nature of competition in the product market.[12]

3.2 Analyzing the Model

We first show that under an assumption of "Decreasing Returns to Attracting Workers" each firm will end up with the same number of workers in the wage-bidding game, up to integer constraints. We shall then use this result to state conditions under which equilibria with and without training exist. Finally, we shall give a detailed interpretation of these conditions.

3.2.1 The Wage-Bidding Game

The following assumption is useful to characterize the equilibrium in the wage-bidding game.

Assumption 3: *$v(n^i, G)$ is decreasing in n^i.*

This assumption needs careful discussion. It says that the gross profit increase resulting from hiring an additional worker from a given pool of size G becomes smaller as n^i increases. Again, whether this assumption holds in a given model depends (i) on the training technology and (ii) on the nature of product market competition, as we will discuss in detail in Section 4. For instance, Assumption 3 is fulfilled for homogeneous Cournot competition with linear inverse demand functions $p = a - x$ and training technology

[12] If firms were wage takers in the labor market, no firm would invest in training regardless of the degree of competition.

$c(n) = \frac{1}{n\delta+1}$, for a wide range of parameters. [13,14]

The first main result contains two important conclusions. First, wage bidding leads to an equal distribution of workers across firms. Second, as argued intuitively in Section 2, wages correspond to the firms' marginal valuations for workers.

Proposition 1 *Suppose that assumptions 1- 3 hold.*
(A) Then the wage-bidding game has an equilibrium such that, up to integer constraints, both firms employ the same number N of trained workers.[15]
(B) In this equilibrium, each educated worker obtains wage offers

$$w^* (N, G) = v (N, G) .$$

(C) There is no equilibrium with $\mid n^j - n^i \mid > 1$.

Proof. See Appendix 1. ■

The intuition for this result is as follows: If Assumption 3 holds and workers are distributed evenly, each firm values its marginal worker more than the competitor would be prepared to pay for him. With an uneven distribution, the firm with the smaller number of workers is willing to pay more for the marginal worker of the competitor than the competitor is prepared to pay for keeping him. Thus, the equilibrium requires an even distribution of workers. Wages correspond to the value of an additional worker, $v (N, G)$.[16] Wages

[13] Examples include $a = 100$, $\delta = 0.01$ and $G = 10$, and for $a = 10$, $\delta = 0.001$ and $G = 100$.

[14] Assumptions 1 and 2 trivially hold in this case, so that all the assumptions of the paper are fulfilled.

[15] When an uneven number of $2N + 1$ workers have been trained, one firm trains N workers, whereas the other firm trains $N + 1$.

[16] It is straightforward to show that any other wage profile where everybody is offered the same wage between $v (N - 1, G)$ and $v (N, G)$ is also an equilibrium with an even distribution of workers. However, these other equilibria are payoff-dominated from the perspective of the firms, since wage costs are higher than in the equilibrium described in Propositon 1. In the following, we use payoff dominance among firms as an equilibrium selection device in the wage-setting game. Since firms make wage offers, this assumption is plausible.

are therefore highest when it pays a lot to escape neck-to-neck competition, that is, competition is intense.

It is important to note that Assumption 3 is sufficient, but not necessary, for the conclusion of Proposition 1. The crucial requirement is that the primitives of the model are such that, starting from an even distribution of workers, firms gain less (in terms of gross profits) from attracting any number k of additional workers than they lose if the competitor attracts k additional workers. This is clearly implied by Assumption 3, but does not require it to hold globally. This idea will be introduced more thoroughly and applied in Section 4.3.

3.2.2 Subgame Perfect Equilibrium

We now analyze the subgame perfect equilibrium. Doing this for a discrete number of workers is tedious, as it requires distinguishing between even and odd numbers. We use a continuous approximation instead, building from the two main insights of the wage-bidding game analyzed in section 3.2.1, which, to repeat, are as follows. First, if Assumption 3 holds, $n^i = n^j = G/2$, up to integer constraints. Second, the equilibrium wage equals the productivity of the marginal worker, $v(n^i, G)$. By the definition in (1), this term reflects both that the firm employs more workers itself and that the competitor employs less workers. Therefore, a natural extension to the continuous case is to define $v(n^i, G) \equiv \frac{\partial \pi}{\partial n^i} - \frac{\partial \pi}{\partial n^j}$ (evaluated at $(n^i, G - n^i)$) and to equate the equilibrium wage with $v(n^i, G)$, that is, the marginal value of poaching an employee for firm i, which consists of the effect of employing more workers oneself $\left(\frac{\partial \pi}{\partial n^i}\right)$ and of reducing the number of workers employed by the competitor $\left(-\frac{\partial \pi}{\partial n^j}\right)$.

With a total number $G = g^i + g^j$ of trained workers, each firm will employ $G/2$ workers at a wage of $v\left(\frac{G}{2}, G\right)$, resulting in long-term profits

$$\Pi\left(g^i,g^j\right) = \pi\left(\frac{G}{2}, \frac{G}{2}\right) - \frac{G}{2}\left[v\left(\frac{G}{2}, G\right)\right] - g^i \cdot I. \tag{2}$$

This result helps to understand under which circumstances equilibria with and without training result.

Proposition 2 *(i) An equilibrium without training exists if and only if*

$$\pi(g,g) - g\cdot[v(g,2g)] - 2gI \leq \pi(0,0) \text{ for all } g \geq 0. \tag{3}$$

(ii) If $\Pi(g^i,g^j)$ *is continuous and quasiconcave in* g^i *and (3) is violated, an equilibrium with training exists.*

Proof. See Appendix 2. ■

Condition (3) simply compares the payoffs in the no-training equilibrium ($\pi(0,0)$) with those in a situation where one firm trains $2g > 0$ workers. The latter payoff is obtained from (2) with $G = 2g$. Part (i) of the proposition does not preclude the simultaneous existence of an equilibrium with training. Part (ii) of the proposition does not necessarily imply that both firms provide training. We will discuss in the next section which cases will occur when we specify different types of product market competition. Before that, we state the following necessary conditions for a symmetric equilibrium where both firms train.

Proposition 3 *A training equilibrium with* $g^i = g^*$ *requires:*

$$\pi(g^*,g^*) - g^*\cdot[v(g^*,2g^*)] - g^*I \geq \pi\left(\frac{g^*}{2},\frac{g^*}{2}\right) - \frac{g^*}{2}\cdot\left[v\left(\frac{g^*}{2},g^*\right)\right] \tag{4}$$

and

$$\frac{\partial\pi}{\partial n^j} - \frac{g^*}{2}\cdot\left(\frac{\partial^2\pi}{(\partial n^i)^2} - \frac{\partial^2\pi}{(\partial n^j)^2}\right) = I, \tag{5}$$

where all derivatives are evaluated at $(n^i,n^j) = (g^*,g^*)$.

Condition (4) merely states that deviating to no training is not profitable. (5) follows immediately from (2), which yields the first-order condition

$$\frac{\partial\Pi}{\partial g^i} = \frac{1}{2}\frac{\partial\pi}{\partial n^i} + \frac{1}{2}\frac{\partial\pi}{\partial n^j} - \frac{1}{2}\left(\frac{\partial\pi}{\partial n^i} - \frac{\partial\pi}{\partial n^j}\right) - \frac{g^*}{2}\left(\frac{\partial^2\pi}{(\partial n^i)^2} - \frac{\partial^2\pi}{(\partial n^j)^2}\right) - I = 0, \tag{6}$$

where all derivatives are evaluated at $(n^i,n^j) = (g^*,g^*)$. Rearranging (6) leads to (5).

To understand (6), note that the total effect of an additional marginal trained worker on gross profits thus has the following four components.

1. The *own productivity effect* ($\frac{1}{2}\frac{\partial \pi}{\partial n^i} > 0$): As workers are distributed equally in the equilibrium of the wage-bidding game, only half of the marginal increase in the number of trained workers becomes effective in increasing gross profits for firm i itself.

2. The *competitor productivity effect* $\left(\frac{1}{2}\frac{\partial \pi}{\partial n^j} < 0\right)$: Half of the additional trained workers will work for the competitor, leading to a negative effect on one's own gross product market profit.

3. *Wages for additional trained workers* $\left(-\frac{1}{2}\left(\frac{\partial \pi}{\partial n^i} - \frac{\partial \pi}{\partial n^j}\right) < 0\right)$: Half of the additional trained workers are employed by the firm under consideration, resulting in additional wage payments of half the wage rate.

4. *Changes in wages per trained worker* $\left(-\frac{g^*}{2} \cdot \left(\frac{\partial^2 \pi}{(\partial n^i)^2} - \frac{\partial^2 \pi}{(\partial n^j)^2}\right)\right)$: The sign of these changes is not fully specified by our assumptions. However, the intuition that additional competition among trained workers drives down wages typically holds if Assumption 3 is satisfied. Appendix 4 contains a technical discussion of the sign of the wage effect.

The first three effects in (6) sum up to $\frac{\partial \pi}{\partial n^j} < 0$. Thus, increasing the number of trained workers in the market marginally is only worthwhile if the negative effect of higher competitor productivity, measured by $\frac{\partial \pi}{\partial n^j}$, is outweighed by a sufficient reduction in wages for inframarginal workers (effect 4).

Our arguments can be linked to familiar results from the literature suggesting that low turnover is necessary for training. In a training equilibrium where both firms train the same amount of workers, there is indeed no turnover by Proposition 1 when Assumption 3 holds.

4 Soft vs. Intense Competition

Next, we provide a more detailed investigation of the claim that training can arise only if product-market competition is sufficiently soft. In all the following the assumptions on the training technology and on product market competition will be such that Assumptions 1 and 2 are satisfied. Assumption 3 will require further discussion.

4.1 Defining soft and intense competition

It is useful to introduce formal definitions of intense and soft competition that are particularly suitable for our training game, but are closely related to familiar concepts of intensity of product market competition.

Definition 1 *Competition for trained workers is intense if*

$$v\left(n, 2n\right) > \frac{\pi(n, n) - \pi(0, 0)}{n} \quad for\ all\ n > 0. \tag{7}$$

Otherwise competition for trained workers is soft.

The definition captures a simple intuition. Using (1), $v\left(n, 2n\right)$ is the marginal value of an additional worker when firms are competing neck-to-neck, that is, the gross profit increase for firm i resulting from poaching a worker when initially $n^i = n^j$. Therefore, under intense competition for trained workers, the marginal value of a worker in such a symmetric situation is higher than the average value of each worker in the industry ($\frac{\pi(n,n)-\pi(0,0)}{n}$). This requirement is related to standard notions of competitive intensity in the product market. For instance, in the case of homogeneous Bertrand competition, (7) always holds, because firms can only earn positive profits if they are more efficient than their competitors. However, (7) not only reflects product market conditions, but also training technology. Intuitively, when the marginal cost reduction brought about by training more workers is decreasing in the number of trained workers already in the firm, this works against condition (7).

4.2 Intense Competition

To show that soft competition is crucial for training to arise, we consider first a situation of intense competition for workers. Our first observation follows immediately from the definition of intense competition, as (3) holds for any level of training costs if (7) holds.

Corollary 1 *If competition is intense, the no-training equilibrium always exists.*

With homogeneous Bertrand competition, the no-training equilibrium is unique, as we show next. Consider two firms who can potentially train arbitrarily many workers, sell homogeneous goods and choose prices simultaneously. Suppose that marginal costs are a decreasing function $c^i \equiv c(n^i)$ of the number of trained workers employed in a firm.

When firms have n^i and n^j workers after the wage bidding game in period 2, Bertrand competition implies that profits are positive if and only if $n^i > n^j$. Hence, competition for workers is intense and Assumption 3 is violated. We obtain the following result:

Proposition 4 *If homogeneous-good duopolists compete in prices, there exists a unique subgame perfect equilibrium in which no firm trains.*

Proof. See Appendix 3 ■

The intuition for the result in proposition 4 is as follows. If both firms have trained the same amount of workers $n^i = n^j = n > 0$, the only way to obtain a positive gross profit is to poach the other firm's worker. As a result, the pure-strategy equilibria of this subgame must be asymmetric. One firm employs all workers and has to pay wages that are so high that the workers are not poached by the competitor. Hence, wages are bid up to $\frac{\pi(2n,0)}{2n}$ and long-term payoffs are $-nI$. As neither firm can cover its training costs, this cannot be an equilibrium. Firms can always obtain zero long-term payoffs by refraining from training. The same logic applies if only one firm invests in training, as this firm will never be able to cover its costs. This illustrates how intense competition works against training.

4.3 Soft competition

We now consider soft competition. We start with the following consequence of Proposition 2.

Corollary 2 *Suppose that Assumption 3 holds and that* $\Pi(g^i, g^j)$ *is quasi-concave in* g^i*. Then there always exists a training equilibrium under soft competition if training costs are sufficiently low.*

Corollary 2 follows from the observation that, with soft competition, condition (3) is violated for sufficiently small values of I.

Next, we provide an example, and we show that with sufficiently strong product differentiation and sufficiently large product markets an equilibrium with training arises. To this end, we consider price competition between two firms producing imperfect substitutes, with demand functions

$$D_i(p_i, p_j) = A - 10p_i + p_j.$$

We specify the training technology as $c_i = 2\exp(-n_i)$. Thus, marginal costs are $c_i = 2$ without training, and they decrease exponentially with training. Simple calculations show that[17]

$$\pi\left(n^i, G - n^i\right) = \frac{10}{159\,201}\left(21A - 398e^{-n^i} + 20e^{-\left(G-n^i\right)}\right)^2.$$

Next, we apply the considerations of the proof of Proposition 1 to show that the wage-bidding game leads to an even distribution of workers with wage

[17] In these calculations, we assume $A > \frac{398}{21}$ to guarantee positive outputs for both firms and arbitrary G, n^i.

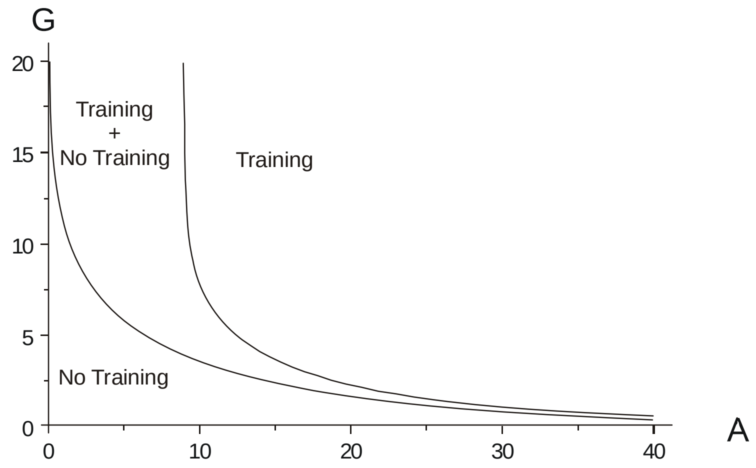

Figure 1: Equilibrium regions for I=0

$\frac{\partial v(N,G)}{\partial n^i}$ for $N = G/2$. This property holds if, for all $k \leq N$, the following condition holds, which is weaker than Assumption 3:

$$\pi (N+k, N-k) - \pi (N,N) \leq k\frac{\partial v(N,G)}{\partial n^i} \leq \pi (N,N) - \pi (N-k, N+k) \tag{8}$$

This condition says that, starting from a symmetric distribution of workers across firms and given wages $\frac{\partial v(N,G)}{\partial n^i}$, neither firm would gain from increasing wage offers slightly so as to attract some number k of the competitor's workers, and no firm would gain from lowering wages slightly. Indeed, we have checked that (8) holds, for instance, for $A = 20, 30$ and 40. Proposition 3 still holds with Assumption 3 replaced by (8) above.

Figure 1 depicts the equilibrium regions for the boundary case $I = 0$.

An increasing market size makes training easier to sustain. The maximum level of training costs which is consistent with a training equilibrium where each firm trains a specific number of g workers is increasing in A. According to (5), a training equilibrium requires

$$\frac{20}{7581}e^{-g}\left(360e^{-g} - 20A - 7524ge^{-g} + 209Ag\right) \leq I;$$

and the left-hand-side of this equation is (linearly) increasing in A.

4.4 The effect of the number of firms

It is possible to extend the model to $M > 2$ firms. Doing so requires some care, however. This starts with the appropriate generalization of Assumption 3 and, more fundamentally, the appropriate generalization of $v(n^i, G)$. The value of an additional worker can now potentially depend on the distribution of workers across competitors, not just on the total number of workers employed by competitors. Proposition 1 can be generalized, however, by replacing Assumption 3 with the requirement that the value of an additional worker is decreasing in n^i, no matter how the remaining workers are distributed across firms.

Using this generalization of Proposition 1, one can then proceed as in Section 3 to provide conditions for training. For a firm that has trained g^i workers when G trained workers are in the industry, long-term payoffs Π^M are

$$\Pi^M\left(g^i, G-g^i\right) = \pi\left(\frac{G}{M}, \frac{G}{M}, ..., \frac{G}{M}\right) - \frac{G}{M}\left[v\left(\frac{G}{M}, G\right)\right] - g^i \cdot I; \qquad (9)$$

where $\pi\left(\frac{G}{M}, \frac{G}{M}, ..., \frac{G}{M}\right)$ denotes gross payoffs when workers are distributed symmetrically across firms; $v\left(\frac{G}{M}, G\right)$ is the value of an additional trained worker in such a situation.[18]

Starting from there, it is straightforward to derive conditions for training equilibria, as in Propositions 2 and 3. Intuition suggests that training is less likely to arise in equilibrium for a large numbers of firms. As argued above, a training equilibrium requires a sufficiently large effect of own training on wages. When there are many firms, however, the effect that a single firm exerts on wages is likely to be small.

[18] This value is well-defined under a standard symmetry assumption that, starting from an equal distribution of workers, the firm's additional profit from hiring another worker does not depend on which competitor the worker comes from.

5 Why do Firms Pay for Training?

In this section we compare and relate our model to existing theories which can explain why firms invest in general or industry-specific skills of their employees.

5.1 Conditions for Firm Sponsored Training

Acemoglu and Pischke (1999) observed that firms will not pay for general or industry-specific training in competitive labor markets, even if workers face credit constraints. All theories of firm-sponsored general training therefore rely on non-competitive wages below the productivity of the worker, which yield rents for the employer. In addition, the gap between productivity and wage is higher at greater levels of skills, which Acemoglu and Pischke (1999) refer to as compressed wage structure. It is then intuitive that if wages are below marginal products and the wage structure is compressed, firms will bear some of the costs of training, even when workers can invest in skills themselves.

5.2 Sources of Rents and Wage Compression

First, rents and a compressed wage structure may result from transaction costs arising from matching and search frictions. Such frictions typically allow firms to keep a fraction of the marginal productivity of the worker as profits, and bargaining between the employee and the employer compresses the wage structure (see Acemoglu 1997).

Second, rents and wage compression can be caused by asymmetric information between the current employer of a worker and other firms. Potential employers may not know the amount of training that the worker has acquired, enabling the initial employer to employ its trained workers for a relatively low wage. This motivates firms to sponsor training, as the wage structure will be compressed.[19] Also, potential employers have less information regarding the ability of workers than current employers. As a consequence, when ability and training are complements, a compressed wage structure emerges, leading to rents for the firms (Acemoglu and Pischke 1998a). Trained workers cannot signal their ability and current employers can deter quitting without paying the full value of training.

A third reason why firms invest in training occurs when specific and general skills are complementary. When a higher level of general skills increases the value of firm-specific skills, the wage structure will be compressed and firms have an incentive to sponsor training (Acemoglu and Pischke 1998b) (see also Franz and Soskice 1995 and Stevens 1994, Kessler and Lülfesmann 2006).

Finally, specific labor market institutions may also compress the structure of wages and may lead to firm-sponsored training. For instance, this has been established for union wage setting by Acemoglu and Pischke (1998b).

5.3 Imperfect Competition in Product Markets

Our model with imperfect competition in the product market provides a novel explanation for a compressed wage structure. Workers are not paid their full value in the wage bidding game, as, for each firm, the value of an additional trained worker is less than the profit reduction of the current employer who loses an employee. As the number of trained workers increases, the wages of trained workers decline. Though the source of wage compression differs from Acemoglu and Pischke (1999), the conclusion is that firms invest in the skills of their employees, as training one additional worker generates rents because all wages fall. By emphasizing a novel source of wage compression, we obtain new insights into the determinants of training. As we will show below, these insights not only concern the nature of product market competition, but also firm size and the geographical density of economic activities.

[19] See Katz and Ziderman 1990 and the formalization by Chang and Wang 1996.

5.4 Empirical Implications

All told, our analysis suggests that soft product market competition is favorable to training, because the costs of preventing turnover are relatively low. Testing this claim empirically is hard, in particular, because finding measures of the intensity of product-market competition that are suitable for empirical analysis is difficult. Measures such as the Herfindahl index are inadequate because of their endogeneity: High concentration, which is often equated with soft competition, may well be the result of underlying competitiveness of the market environment (Sutton 1991, Boone 2007). Existing empirical evidence is nevertheless supportive of the mechanisms identified here. For instance, several authors have observed that training tends to be lower in regions where the density of economic activities is high (Mühlemann and Wolter 2006, Brunello and Gambarotto 2007). This evidence fits well with our theoretical results. In agglomerations, firms are more prone to poaching, because competition for workers is intense. Starting from a training equilibrium, firms would therefore have to offer high wages to prevent turnover. Similarly, the observation that large firms train more than small firms (Wolter et al. 2006, Bassanini et al. 2007) is consistent with our ideas, because large firms can exert a stronger influence on wages with their training decisions than small firms.

Clearly, however, a more direct test of the relation between product market competition and training would be desirable. An ideal design would use a natural experiment that can be interpreted as an increase in competition for some sets of firms in an economy, but not for others.[20]

[20] For instance, stricter cartel laws in a small country are suitable candidates, because they are likely to have strong effects only on those firms that are not exposed to international competition (See Bühler et al. 2005 for an application to Switzerland).

6 Welfare Results and Policy Discussion

Our analysis is partly motivated by different institutional arrangements in labor markets across the OECD. In some countries, such as Germany, firms offer apprenticeships to their workers. The knowledge acquired in such programs is typically applicable in other firms of the same industry. Nevertheless, firms bear part of the training costs. In contrast, the U.S. economy appears to generate less training than Germany or Japan, at least it the initial stage of a worker's life (Blinder and Kruger 1996, Acemoglu and Pischke 1998).[21]

For simplicity, we suppose that the German and the U.S. labor and product markets are completely separated. Each of the two countries corresponds to one set of parameters of the game. Our model allows two different types of explanations of the apparent cross-country differences. First, obviously, the relevant parameters of the game could differ across countries. Roughly speaking, Germany could be in a regime where a training equilibrium exists, and the U.S. in a regime where it does not. The differences might come from industry characteristics such as the intensity of competition. Alternatively, state interventions might have affected the payoff functions. Second, one could think of the game as being the same in both countries, with both countries in different equilibria. German firms have coordinated on the training equilibrium, while US firms are in the no-training equilibrium.

Regarding welfare, we have already seen in the example of Section 2 that, in the presence of multiple equilibria, firms may be worse off in the training equilibrium than in the no-training equilibrium. As trained workers and consumers are better off when firms invest in training, training in the presence of multiple equilibria is socially desirable if (1) firms benefit from training or (2) consumers and workers have a sufficiently large weight in the social welfare function when firms prefer no training.[22] If firms benefit from training,

[21]Training investment in later stages of a worker's life is relatively low in Germany (OECD 1999), but the differences in the initial stage appear to be more substantial.

[22]In all the examples we have investigated, training is socially desirable when the social

government intervention is unnecessary if firms coordinate on the payoff-dominant equilibrium. If firms coordinate on the no-training equilibrium when training would yield higher welfare but lower total payoffs, there could be a role for government to induce training. On the one hand, the state can offer complementary investments such as schooling facilities where costless classroom education is provided. On the other hand, temporary support for general training investment may establish a social norm which will remain after direct support has been withdrawn. Apart from granting direct financial aid, governments could provide such temporary support by promoting universal acceptance of certificates from apprenticeships.

Perhaps the most important implication of our model is that increasing competitive intensity might destroy the training equilibrium. This suggests a crucial question: Can apprenticeships survive as firms are becoming more and more exposed to competitors from countries without such programs?

7 Conclusions

We provided a theory of industry-specific training, which relies on imperfect product market competition to generate equilibria with general training in an environment where turnover is endogenous. Training equilibria exist for plausible parameter values, possibly together with the no-training equilibrium. We do not claim that training is likely in all industries. The most important conditions concern the training technology and the intensity of product market competition. Competition must be sufficiently soft, and returns to training must decrease sufficiently fast for turnover to be avoided and training to arise in equilibrium. Otherwise firms would have strong incentives to escape neck-to-neck competition by hiring the competitor's worker.

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welfare function is the unweighted sum of producer surplus, wages and consumer surplus.

8 Appendices

8.1 Appendix 1: Proof of Proposition 1

To show existence, we restrict ourselves to the case where $G = 2N$ is even; the case $G = 2N + 1$ is similar. We first show that, given the competitor's wage offers $w^*(N, G)$, lowering wages is not profitable. Suppose the firm reduces its wage offer to k workers ($k \leq N$) so that it ends up with only $N - k$ workers.[23] This deviation is not profitable if

$$\pi(N, N) - k \cdot w^*(N, G) \geq \pi(N - k, N + k).$$

As $w^*(N, G) = \pi(N + 1, N - 1) - \pi(N, N)$, this is equivalent to:

$$\pi(N, N) - \pi(N - k, N + k) \geq k(\pi(N + 1, N - 1) - \pi(N, N)),$$

which is implied by repeated application of Assumption 3. Thus, downward deviation is not profitable. As to upward deviations, a higher wage offer for one worker would yield an increase in gross profits of $\pi(N + 1, N - 1) - \pi(N, N)$, which is exactly offset by the additional wage payments $w^*(N, G)$. By Assumption 3, attracting any further worker would yield additional gross profits smaller than $\pi(N + 1, N - 1) - \pi(N, N)$ and thus smaller than the additional wage payment. Hence, there are no profitable deviations.

We finally show that there is no equilibrium with $n^i < n^j - 1$. The willingness of firm i to pay for an additional worker is $\pi(n^i + 1, G - n^i - 1) - \pi(n^i, G - n^i)$. By Assumption 3, for $n^i < n^j - 1$, this is greater than $\pi(n^j, G - n^j) - \pi(n^j - 1, G - n^j + 1)$, which is the value of the last worker that firm j employs.

[23] To avoid technicalities associated with tie-breaking, we use a flexible tie-breaking rule: If the firms offer the same wage to a worker, whether he stays in his original firm or moves is determined by equilibrium requirements. A detailed formal description of this procedure is available on request.

8.2 Appendix 2: Proof of Proposition 2

(i) Consider firm 1. By (2) deviating from $(0,0)$ to $g^1 > 0$ gives a profit of $\pi\left(\frac{g^1}{2}, \frac{g^1}{2}\right) - \frac{g^1}{2}\left[v\left(\frac{g^1}{2}, g^1\right)\right] - g^1 \cdot I$ as compared to $\pi(0,0)$ without training. With $g = \frac{g^1}{2}$, the statement follows: The left-hand side of (2) gives the deviation profit for arbitrary deviations from (symmetric) no training; the right-hand side corresonds to the profits without training.

(ii) Because training levels can be chosen continuously, the strategy set is convex. Because product market profits are bounded above and training costs increase above all bounds as g^i increases, by eliminating dominated strategies, one can assume w.l.o.g. that strategy spaces are compact. Both players' payoff functions are continuous and quasiconcave by assumption of the proposition and the strategy space is non-empty. Thus, the game has a pure-strategy equilibrium according to Proposition 8.D.3 in Mas-Colell et al. (1995). By Proposition 2(i), this equilibrium must involve training.

8.3 Appendix 3: Proof of Proposition 4

The proposition is proved by contradiction. Suppose that $g^i \geq 0$ and $g^j \geq 0$ with $g^i > 0$. After the wage bidding game, firms have $n^i(n^j)$ trained workers, with $g^i + g^j = n^i + n^j$. We distinguish three cases.

Case I: $n^i = n^j$
As $\pi(n^i, n^j) = 0$, long-term payoffs for both firms are equal or smaller than $-g^i I$ and $-g^j I$. This cannot be an equilibrium as firm i can always obtain zero long-term payoffs by choosing $g^i = 0$ and refraining from poaching.

Case II: $n^i > n^j$
We first observe that such a constellation implies $n^j = 0$. Trained workers are of no value for firm j if $n^i > n^j$. Hence, $n^j > 0$ but $n^i > n^j$ could only occur if wages for trained workers are zero. However, this cannot be an equilibrium in the wage bidding game as firm i benefits from poaching more

workers and would be willing to pay

$$\pi\left(n^i+1,n^j-1)\right)-\pi\left(n^i,n^j\right)>0$$

for an additional skilled worker from firm j.

Let us therefore suppose that $n^i = g^i + g^j$ and $n^j = 0$. Then firm j is willing to pay $\frac{\pi(g^i+g^j,0)}{g^i+g^j}$ for each of the trained workers employed by firm i. With such wage offers gross product market profits - total wage payments would be zero for firm j and equal to the situation with $n^j = 0$. As firm i has to pay the sum $\pi(g^i + g^j, 0)$ for all of its trained workforce to avoid poaching by firm j, its long-term payoff is $-g^i I < 0$. Hence, this is again a contradiction, as firm i can always secure a long-term payoff of 0 by setting $g^i = 0$ and by participating in the wage bidding game for trained workers of firm j if there are some.

Case III : $n^i < n^j$
By the same argument as in Case II we must have $n^i = 0$. Hence, the long-term payoff of firm i is $-g^i I < 0$ as $\pi(0, g^i + g^j) = 0$. As in Case II, firm i can profitably deviate by setting $g^i = 0$. This completes the proof.

8.4 Appendix 4: The Wage Effect

We now argue that increasing training levels tend to reduce the wage level, i.e., $\frac{\partial^2\pi}{(\partial n^i)^2} - \frac{\partial^2\pi}{(\partial n^j)^2} < 0$. Clearly, this is true if π is concave as a function of n^i and convex as a function of n^j. Also, Assumption 3, i.e., concavity of $\pi(n, G-n)$ as a function of n implies that $\frac{\partial^2\pi}{(\partial n^i)^2} + \frac{\partial^2\pi}{(\partial n^j)^2} - 2\frac{\partial^2\pi}{\partial n^i \partial n^j} < 0$. Thus, unless $\frac{\partial^2\pi}{\partial n^i \partial n^j} - \frac{\partial^2\pi}{(\partial n^j)^2}$ is very positive[24]

$$\frac{\partial^2\pi}{(\partial n^i)^2} - \frac{\partial^2\pi}{(\partial n^j)^2} = \frac{\partial^2\pi}{(\partial n^i)^2} + \frac{\partial^2\pi}{(\partial n^j)^2} - 2\frac{\partial^2\pi}{\partial n^i \partial n^j} + 2\left(\frac{\partial^2\pi}{\partial n^i \partial n^j} - \frac{\partial^2\pi}{(\partial n^j)^2}\right) < 0$$

and the wage effect is therefore positive.

[24] This is not likely: Typically, at least $\frac{\partial^2\pi^i}{\partial n^i \partial n^j} < 0$, roughly speaking, because the positive effect of trained workers on the own mark-up of a firm is higher when the other firm has less trained workers and thus faces a smaller market share.

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