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# A Product-Market Theory of Industry-Specific Training

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**ABSTRACT:** We develop a product market theory that explains why firms provide their workers with skills that are sufficiently general to be potentially useful for competitors. We consider a model where firms first decide whether to invest in industry-specific human capital, 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 and returns to the number of trained workers decrease sufficiently, firms may invest in non-specific training if others do the same, because they would otherwise suffer a competitive disadvantage or need to pay high wages in order to attract trained workers.

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

**JEL:** D42, L22, L43, L92.

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# 1 Introduction

Economists have long wondered why firms provide incentives for employees to invest in productivity-enhancing general human capital that is useful outside the firm. After all, general training investments make the workers potentially more valuable for other employers. The famous arguments by Becker (1964) and Mincer (1974) suggest that, with competitive labor markets, firms have no incentive to bear the costs of general worker training, as the associated rents accrue fully to the employees: If training investments are contractible, workers will obtain the full increase in marginal product resulting from the investment. However, these predictions seem at odds with reality (Acemoglu and Pischke 1998, Franz and Soskice 1995, Katz and Ziderman 1990, OECD 1999). In some countries, such as Germany or Switzerland, firms voluntarily pay for apprenticeships that provide workers with general skills.<sup>1</sup> In addition, firms continually pay for on-the-job training of incumbent workers.<sup>2</sup>

Similar arguments apply with a vengeance to the case of industry-specific training, where the skills acquired are valuable for other firms in the same industry, but not outside of the industry. Even though this case is intermediate between specific and fully general training, firms' incentives to provide such training would appear to be even lower than for general training. As a trained worker's knowledge is only valuable within the same industry, he is most likely to work for a competitor if he leaves a firm. Thus, not only will the trained worker be of no value for the original employer, in addition, he will strengthen the competitor.

Nevertheless, this paper will demonstrate that it is possible to explain industry-specific training. Our explanation will rely on imperfect competition

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<sup>1</sup>For instance, Bardeleben et al. (1995) calculate the net costs per apprentice per year in German industry as DM 20509 per year if fixed costs are included, and DM 9194 if they are not. A considerable part of this training is general - for instance, apprentices spend about 65 days per year in external schools and courses.

<sup>2</sup>Several recent 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 Villhuber (1997, 1998).

in the product market. We argue in the setting of a three-stage game. In a first stage (*training stage*), two initially identical firms decide on how many workers they want 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. Training and turnover decisions in the first two stages determine the distribution of trained workers and thereby product market profits: We assume that a firm's *gross profits*, that is, product-market profits excluding the costs of training and wages, depend positively on its own number of trained workers and negatively on the competitor's, as trained workers increase productivity, for instance, by reducing marginal costs.

When firms compete for trained workers in the second stage, equilibrium wages will correspond to the marginal contribution of a trained worker to gross profits, for a given total supply of workers. This marginal value has two components. First, an additional worker in the own firm has a direct positive effect, because it increases the own productivity. Second, the fact that the competitor does not employ this worker helps to increase profits because it weakens the competitor.

Our main result is that there often is a symmetric equilibrium with positive training levels. To see why, suppose all firms train. Consider the incentives of a firm to reduce its training activities and poach trained workers from the competitor instead. A first rough intuition is that the reduction in the supply of trained workers will result in an increase in wages. Rather than paying high wages to poach workers, firms might therefore prefer to train workers to keep the ex-post wages relatively low.

For the intuition described to be correct, however, it is crucial that the wage, that is, the marginal value of the worker, is indeed a decreasing function of the number of trained workers in the market. Whether this is so depends on several factors. First, the training technology is important: Clearly, a declining wage is more likely the more rapidly the cost effect of employing additional workers declines. Second, product market characteristics will turn

out to play a role.

As a result, training will only arise in equilibrium when competition on product markets is sufficiently soft, meaning that the profit increase from becoming more efficient than a competitor is not much higher than the profit increase when two symmetric firms both reduce their marginal costs by the same amount. For instance, competition becomes softer when products are more differentiated, or when one moves from homogeneous Bertrand to Cournot competition.

The role of the intensity of competition for training is captured in several results. For instance, we show that there can be no industry-specific training with homogeneous price competition. However, in a model of differentiated price competition, a large market size or a high extent of product differentiation strengthen the training equilibria, and quantity competition makes the equilibrium more likely than price competition.

Therefore cross-sectoral differences in the intensity of competition may play a role in explaining differences in training expenditures.<sup>3</sup> Similarly, the widespread perception that firms have recently become less willing to invest in training might be the result of increased product market competition. In this respect, our paper goes beyond existing theory, which assumes perfect product market competition and thus cannot use different intensities of product market competition as an explanatory variable.

It is important to emphasize, however that even very soft product market competition, for instance, product market monopolies for the firms under consideration are not sufficient to guarantee a training equilibrium. In addition, the training technology must display sufficiently decreasing returns, meaning that the cost reduction brought about by an additional trained worker is decreasing in the number of workers already employed.

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<sup>3</sup>The above-mentioned study by Bardeleben et al. (1995) shows great differences in training intensities across different sectors. Net variable expenditures per worker and year differ between DM 1002.- (food industry) and DM 20,565 (chemical industry). In terms of gross expenditure, the differences are still large, ranging from DM 12,142.- (road construction) to DM 32,027 (chemical industry).

Apart from the training equilibrium, an equilibrium without training may exist. When no competitor trains, the value of training for an individual firm may even be negative, so that the firms under consideration would be willing to pay to prevent their workers from training. Intuitively, this is true because trained workers can threaten to join the competitor, which would reduce the payoff of the firm that trains compared to a situation where it has not trained workers. In view of the possible occurrence of multiple equilibria, we discuss governmental intervention to move firms into the training equilibrium. This suggests that cross-country differences in the extent to which such coordination mechanisms are established might explain the differences in general worker training observed in OECD (1999), Acemoglu and Pischke (1998), Booth and Snower (1996).

Our theory of industry-specific training is obviously related to familiar explanations of general worker training. Such explanations typically rely on labor market imperfections caused by asymmetric information.<sup>4</sup> Essentially, if present employers can observe ability or training investments better than potential future employers, the latter will face a lemon's problem.<sup>5</sup> As a result, it is difficult for the employee to sell herself on the job market. The original employer enjoys ex post informational monopsony power, the anticipation of which creates incentives to finance general training. While our theory of industry-specific training focuses on product market imperfections and does not involve asymmetric information, it shares the feature of multiple equilibria with the models of general training that rely on asymmetric information in the labor market.<sup>6</sup>

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<sup>4</sup>For a survey of such explanations see Acemoglu and Pischke (1999). These authors also discuss some alternative theories that do not rely on asymmetric information (see also Stevens (1994), Kessler and Lulfesmann (2000)).

<sup>5</sup>Acemoglu and Pischke (1998) deal with the case of asymmetric information about ability; Katz and Ziderman (1990) and Chang and Wang (1996) consider asymmetric information about training investments.

<sup>6</sup>See Katz and Ziderman (1990), Chang and Wang (1995, 1996), Abe (1994), Prendergast (1992), Glaeser (1992), Acemoglu (1997) and Acemoglu and Pischke (1998).



However, our paper covers new ground in several respects. For instance, our emphasis on the interactions between labor and product markets not only allows us to draw a connection between the intensity of competition and training. In addition, we can show how product market competition affects wages for trained workers: Essentially, with more intense product market competition, the workers enjoy greater bargaining power and wages increase. Thus, we see our contribution not only as another theory of general worker training, but also as a step towards an integrated analysis of product and labor markets. In the following, we spell out these arguments in more detail. In section 2, we introduce the assumptions of our model. In section 3, we use two very simple examples to show how training levels might depend on the intensity of competition. Section 4 provides more general results on the topic. In section 5, we discuss policy implications. Section 6 concludes.

## 2 The Model

The structure of the model is as follows. In period 1, firms  $i = 1, 2$  simultaneously choose their human capital investment levels  $g^i \in \{0, 1, 2, \dots\}$ . Think of  $g^i$  as the number of its employees receiving training. Training a worker costs  $I > 0$  for a firm.<sup>7</sup> Denote firm  $i$ 's trained workers as  $i_1, \dots, i_m, \dots, i_{g^i}$ . At the beginning of period 2, firm  $i$  can make individual wage offers  $w_{i,i_m}(g^i, g^j)$  for each of their own workers and  $w_{i,j_m}(g^i, g^j)$  for each of the competitor  $j$ 's worker ( $j \neq i$ ). In principle, we allow wages to differ even for individuals who have the same level of human capital or belong to the same firm.<sup>8</sup> We normalize wages of non-trained workers to zero. Further, to capture the notion that human capital is industry-specific, that is, useless outside the industry,

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<sup>7</sup>As the incentive of workers to acquire capital that is not firm-specific is undisputed, we ignore the possibility of training investments by workers and deliberately assume that the entire training costs are borne by the firm.

<sup>8</sup>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.

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.<sup>9</sup> Denote the number of trained workers in firm  $i$  at the end of period 2 as  $n^i$ . Employing trained workers is beneficial for the present employer; it could for instance help to reduce production costs, or to increase demand by improving product quality. This feeds into 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 increasing in  $n^i$  and decreasing in  $n^j$ .*

Intuitively, the higher the number of trained workers in a firm, the greater productivity and thus the higher the market profit. The higher the number of trained workers in the competitor's firm, the higher the competitor's productivity and thus the lower the own profit.

Assumption 1 contains several implicit statements about the training technology and product market competition. To start with, note that  $\pi$  is a function of  $n^i$  and  $n^j$ , not of  $g^i$  and  $g^j$ . This 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.<sup>10</sup> Second, training a worker and hiring a trained worker are perfect substitutes.<sup>11</sup> We use perfect substitutability to express the idea that human capital is not firm-specific, and 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

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<sup>9</sup>We use a flexible tie-breaking rule: if  $w_{i,i_m} = w_{j,i_m}$ , whether the employee stays in his original firm or moves is determined by equilibrium requirements.

<sup>10</sup>This is compatible with the assumptions in training theories that are based on labor market imperfections.

<sup>11</sup>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 worker is better known.

function  $\pi$  does not depend on  $i$  directly, only on the number of trained workers.

It will sometimes be convenient to assume  $\pi^i(n^i, n^j)$  is defined for arbitrary positive numbers, not just for integers:  $n^i \notin N$  refers to situations where at least one worker works part-time. In addition, we shall suppose that  $\pi$  is differentiable. We use the following terminology:

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

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

where  $n^i(g^i, g^j)$  denotes equilibrium number of workers in the subgame  $(g^i, g^j)$ .<sup>12</sup>

The game structure is summarized in the Table 1.

**Table 1: Game Structure**

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

We can treat this game as a two-period game, as all the relevant information about period 3 is contained in the reduced form profit  $\pi^i(n^i, n^j)$ . Finally, we impose an assumption on product market competition that is slightly more restrictive than Assumption 1.

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

Thus, gross profits increase if, starting from a symmetric situation, both firms increase the number of workers by the same amount.

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<sup>12</sup>The notation requires that a unique subgame equilibrium exists or that the resulting net product market profits are independent of the equilibrium.

### 3 Motivating Examples

To gain some intuition for the conditions under which training might arise, we provide two examples which are simplified in two important respects, but can nevertheless highlight the main ideas of our general approach. First, training is quite unrealistically described as a  $(0, 1)$ -decision, so that each firm is limited to training one worker at most, that is,  $g^i \in \{0, 1\}$ .<sup>13</sup> Second, we choose specific numerical values for gross product market profits rather than allowing for a full-fledged model of oligopolistic competition. The numerical values are consistent with Assumptions 1 and 2, however. In our first example, they are chosen so as to reflect soft competition; in the second example, they correspond to intense competition.

#### 3.1 Soft Competition: The Set-Up

Consider the following constellation of gross profits:

- *Training decisions*  $g^i = 0; i = 1, 2$ : If both firms do not train, they share the market at 0.5 units of gross profits each, that is,  $\pi(0, 0) = 0.5$ .
- *Training decisions*  $g^i = 1$  for some firm,  $g^j = 0$  for the other firm: gross profits for the firm that trains are  $\pi(1, 0) = 1$ ; gross profits for the firm without a trained worker are  $\pi(0, 1) = 0.2$ .
- *Training decisions*  $g^i = 1; i = 1, 2$ : If both firms enter the product market stage with one trained worker, profits are  $\pi(1, 1) = 0.8$ .

Finally, as a tie-breaking procedure we assume that the worker stays with the firm where it was trained when both firms offer the same wage.

The set-up is consistent with Assumption 1: No matter whether the competitor has trained or not, employing a trained worker increases gross profits.

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<sup>13</sup>The only value of hiring a second trained worker is thus that the competitor cannot take advantage of him. Hence, if one firm employs both trained workers, its payoffs are the same as in the case with one trained worker.

Similarly, whether the firm employs a trained worker or not, gross profits fall if the competitor employs a trained worker. Also, Assumption 2 holds: gross profits are higher when both firms have trained than when neither has. The set-up reflects soft competition in the sense described in the introduction: The profit increase from becoming more efficient than the competitor is not much higher than the profit increase when two symmetric firms both reduce their marginal costs by the same amount.

### 3.2 Soft Competition: The Training Equilibrium

With product market competition reduced to simple numerical values, we can restrict attention to training and wage-setting decisions and solve the game by backward induction. Intuitively, bidding in the labor market at stage 2 entails wages equal to the minimum of the two firms' marginal valuations for a worker.

If only one worker has been trained, the firm that employs him, say firm 1, has profits 1; if he works for the competitor, the gross profit falls to 0.2. Hence, both firms have a marginal valuation of 0.8 for the worker, so that the wage, which we denote as  $w^1$ , is 0.8.<sup>14</sup>

If both firms have trained one worker, their profits are 0.8; if the competitor were to employ the worker, profits would drop to 0.2. Thus, the marginal valuation for having one of the workers (rather than none) is 0.6. However, the marginal valuation for having two workers rather than one is much lower: Hiring a second worker would increase profits from 0.8 to 1. Hence, denoting the equilibrium wage offered by both firms to each worker as  $w^2$ , we obtain  $w^2 = 0.2 = 1 - 0.8$ , and both trained workers will stay with their original firm. Importantly, training therefore not only affects gross profits, but also wages. When more workers are trained, the wage level is lower. This effect is important for training to arise in equilibrium.

With the second-period wages determined in this fashion, the game can be reduced to the simple matrix given in Table 2; where T corresponds to

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<sup>14</sup>In the more general notation of Section 2, this would read  $w_{11}(1, 0) = w_{21}(1, 0) = 0.8$ .

the case that the firm employs a trained worker and NT to the case that he does not.  $I$  corresponds to training costs.

Table 2: **Soft Competition Example**

	T	NT
T	$0.8 - w^2 - I, 0.8 - w^2 - I$	$1 - w^1 - I, 0.2$
NT	$0.2, 1 - w^1 - I$	$0.5, 0.5$

The first observation confirms the intuition that the provision of industry-specific training cannot be taken for granted.

**Observation 1** *An equilibrium without training exists for all  $I \geq 0$ .*

Intuitively, if only one firm trains, both firms are worse off than without training. Essentially, the worker, who gets  $w^1 = 0.8$ , extracts the entire difference between the gross profits of a firm that has a trained worker and the profits of a firm that has none. The fact that workers are likely to leave to the competitor makes firms who provide industry-specific training particularly vulnerable.

On the other hand, the problem is much less pronounced when both firms have trained their workers. In fact, a training equilibrium where both firms train exists if training costs are sufficiently low.

**Observation 2** *If  $I \leq 0.4$ , a training equilibrium exists.*

The intuition is simple: Suppose one firm trains. Training by the other firm increases the supply of trained workers and lowers their wages as marginal profits from hiring more trained workers decline and the bidding game becomes less fierce. For sufficiently small training costs, this wage effect makes training by both firms an equilibrium.

The last observation indicates that it is possible that both firms are better off with training than without.

**Observation 3** *If  $I \leq 0.1$ , long-term payoffs of each firm are higher in the training equilibrium than in the no-training equilibrium.*

### 3.3 Intense Competition

The preceding example demonstrated that industry-specific training may be provided in equilibrium provided training costs are low. To show that soft competition is crucial for training to arise, we consider next an example that reflects a situation of intense competition in the product market. This example will also help to dispel the potential misconception that an increasing number of trained workers necessarily leads to a fall in the wage.

To this end, modify the above example by setting  $\pi(g^i, g^j) = 0$  except when  $g^i = 1$  and  $g^j = 0$ ; in which case  $\pi(1, 0) = 1$  as before. Thus competition is intense in the Bertrand sense that only firms that are more efficient than their competitors can obtain positive profits. Table 3 describes the long-term payoffs, which can be understood by analyzing the wage-bidding.

Table 3: **Intense Competition Example**

	T	NT
T	$1 - 2w^2 - I, -I$	$1 - w^1 - I, 0$
NT	$0, 1 - w^1 - I$	$0, 0$

If both firms have trained, the only way to obtain a positive gross profit of 1 is to poach the other firm's worker. As a result, the equilibria must be asymmetric. One firm employs both workers and pays wages that are so high that it is not better off than the other. Hence, wages must be  $w^2 = 0.5$ . As neither firm can cover its training costs, this cannot be an equilibrium. They can always obtain zero profits by refraining from training. This illustrates how intense competition works against training.

If one firm has trained, it would lose 1 unit of gross profit from poaching by the competitor; and the competitor would win 1 unit. Thus,  $w^1 = 1$ . Note that, if the competitor trains, gross profits cannot be affected by training. An asymmetric equilibrium with only one firm training cannot exist either: If only one firm has trained, both firms value the worker at 1. Hence,  $w^1 = 1$ , so that net profits of the firm who trained the worker are 0, and the long-term

profits are negative whenever training costs are positive.

### 3.4 Summary

The examples suggest several conclusions. First, training additional workers can lead to a fall in wages. Second, when competition is sufficiently soft, a training equilibrium may exist. While these examples illustrate the potential role of the intensity of competition, the ad-hoc payoff structure and the restriction to one trained worker per firm are unsatisfactory. In the following, we shall therefore show that the intuition is nevertheless not misleading.

## 4 Analyzing the General Model

We now return to the more general model of Section 2 where firms can train arbitrary numbers of workers, and where product market profits result from more general kinds of oligopolistic interaction. 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.

### 4.1 The Wage-Bidding Game

We first state conditions under which the wage-bidding game will lead to an even distribution of educated workers across firms, given that  $G$  workers have been trained in period 1.

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 if the own number of trained workers is  $n^i$  and the total number is  $G$ , we write

$$v(n^i, G) = \pi(n^i + 1, G - n^i - 1) - \pi(n^i, G - n^i).$$



Note that the marginal valuation  $v(n^i, G)$  is positive for two reasons. First, the more trained workers a firm itself employs, the lower its costs and the higher its gross profits. Second, the smaller the number of players employed by the competitors, the higher their costs and the higher firm  $i$ 's product market profits.

The following definition will be crucial.

**Definition 1** *If  $v(n^i, G)$  is decreasing in  $n^i$ , we shall say that there are Decreasing Returns to Attracting Workers (DRAW).*

In the Soft Competition Example of Section 2, condition (DRAW) holds: If both firms have trained, having one worker rather than none is worth 0.6 units, whereas poaching the second worker is worth only 0.2 units. In the Intense Competition Example, (DRAW) is violated, because if both firms have trained, only firms that employ both workers have positive profits.

Intuitively,  $v(n^i, G)$  reflects aspects of technology and product market competition. Technology determines how large the cost reduction is that arises from having an additional trained worker. Product market competition determines how this cost reduction (and the concomitant cost increase of the competitor) translates into higher profits.

The first main result contains two important conclusions. First, if (DRAW) holds, wage bidding will be such that workers are split equally across firms. Second, as argued intuitively in the examples in Section 3, wages correspond to the firms marginal valuation for attracting another trained worker.

**Proposition 1** *Suppose that assumptions 1- 2 and (DRAW) 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.*<sup>15</sup>

(B) *In this equilibrium, each educated worker obtains wage offers*

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

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<sup>15</sup>When an uneven number of  $2N + 1$  workers have been trained, one firm trains  $N$  workers, whereas the other firm trains  $N + 1$ .

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

**Proof.** See Appendix.<sup>16</sup> ■

The intuition for this result is as follows: If (DRAW) holds and workers are distributed evenly, each firm values an additional worker less than the competitor values keeping this worker. With an uneven distribution, the firm with the smaller number of workers is willing to pay more for at least one of the competitor's worker than he is prepared to pay for keeping him. Thus, equilibria must result in an even distribution of workers. Wages correspond to the value of an additional worker,  $v(N, G)$ .<sup>17,18</sup> Consistent with the examples of Section 3, wages are therefore highest when it pays a lot to be better than the competitor, that is, competition is intense.

## 4.2 Subgame Perfect Equilibrium

We now analyze the subgame perfect equilibrium of the entire game.

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. The two main insights of the wage-bidding game analyzed in section 4.1 are: First, if assumption (DRAW) holds,  $n^i = n^j = G/2$ , up to integer constraints. Second, the equilibrium wage equals the productivity

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<sup>16</sup>The result in the appendix uses a slightly weaker requirement than (DRAW) which is useful for the product differentiation example in section 4.3.

<sup>17</sup>The same equilibrium obtains in a competitive labor market framework when firms take wages and demand for trained workers of other firms as given. Therefore, equilibria with training can occur in a competitive labor market with demand externalities. Details are available from the authors upon request.

<sup>18</sup>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 Pareto-inefficient from the firms' point of view, since wage costs are higher than in the equilibrium described in Proposition 1. In the following, we assume that the firms achieve an equilibrium distribution of workers at minimal wage costs, i.e., we use the Pareto criterion among firms as a selection device. Since firms make wage offers, this assumption is plausible.

of the marginal worker,  $v(n^i, G)$ . 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 suppose that the equilibrium wage equals this quantity:  $v(n^i, G)$  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  $\left(-\frac{\partial \pi}{\partial n^j}\right)$ .

Using these two results from the discrete game to approximate the second period equilibrium in the continuous game, we immediately obtain

**Lemma 1** *Suppose (DRAW) holds. If firms choose training levels  $g^i$  and  $g^j$  and the second-period training equilibrium is played, firm  $i$ 's long-term payoffs in the continuous approximation of the game are*

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

This result implies a simple condition for an equilibrium without training.

**Proposition 2** *Suppose that (DRAW) holds. An equilibrium without training exists if and only if*

$$\pi(g, g) - g \cdot [v(g, 2g)] - \pi(0, 0) - 2gI \leq 0 \text{ for all } g \geq 0. \quad (1)$$

**Proof.** Consider firm 1. By Lemma 1, 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  $\pi(0, 0)$  in equilibrium. With  $g = \frac{g^1}{2}$ , the statement follows. ■

The proposition clearly shows that intense competition works in favor of an equilibrium without training. For sufficiently low investment costs, (1) will be violated if

$$\frac{\pi(g, g) - \pi(0, 0)}{g} > v(g, 2g) \quad (2)$$

for some  $g > 0$ , that is, if the average increase in gross profit per additional worker from a symmetric situation without training to a situation with training is greater than the wage cost per worker, which is his marginal

value, starting from symmetry. Thus, if the value of getting ahead of the competitors,  $v(g, 2g)$ , is small relative to the average profit effect of each additional worker per firm in a symmetric setting, there can be no symmetric training equilibrium.

Next, we give a condition under which there is an equilibrium with training, but no equilibrium without training.

**Proposition 3** *Suppose that (DRAW) holds and (1) is violated. An equilibrium with training exists.*

**Proof.** Both players' payoff functions are continuous. 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. Thus, the game has a pure-strategy equilibrium. By Proposition 2, this equilibrium must involve training. ■

The proposition does not necessarily imply that the training equilibrium is symmetric. Necessary conditions for such a symmetric training equilibrium are the following.

**Proposition 4** *Suppose (DRAW) holds. A training equilibrium with  $g^i = g^*$  requires:*

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

and

$$\frac{\partial \pi}{\partial n^j} - \frac{g^*}{2} \cdot \left( \frac{\partial^2 \pi}{(\partial n^i)^2} - \frac{\partial^2 \pi}{(\partial n^j)^2} \right) = I, \quad (3)$$

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

The first condition merely states that deviating to no training is not profitable. The second condition follows immediately from the first-order condition

$$\frac{\partial \Pi}{\partial g^i} = \frac{1}{2} \frac{\partial \pi}{\partial n^i} + \frac{1}{2} \frac{\partial \pi}{\partial n^j} - \frac{1}{2} \left( \frac{\partial \pi}{\partial n^i} - \frac{\partial \pi}{\partial n^j} \right) - \frac{g^*}{2} \left( \frac{\partial^2 \pi}{(\partial n^i)^2} - \frac{\partial^2 \pi}{(\partial n^j)^2} \right) - I = 0, \quad (4)$$

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

To understand (4), note that the total effect of an additional marginal trained worker on gross profits thus has the following four components.

(OPE) The *own productivity effect*  $\left(\frac{1}{2} \frac{\partial \pi}{\partial n^i} > 0\right)$

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  $i$  under consideration.

(CPE) The *competitor productivity effect*  $\left(\frac{1}{2} \frac{\partial \pi}{\partial n^j} < 0\right)$

The second half of the increase in trained labor will end up with the competitor, leading to a negative effect on one's own gross product market profit.

(ATW) Wage payments to *additional trained workers*  $\left(-\frac{1}{2} \left(\frac{\partial \pi}{\partial n^i} - \frac{\partial \pi}{\partial n^j}\right) < 0\right)$

As half of the additional trained labor is employed by the firm under consideration, this results in additional wage payments of half the wage rate.

(WTW) 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 WTW is not fully specified by our assumptions. However, the intuition that additional competition among trained workers drives down wages typically holds if Condition (DRAW) is satisfied. Appendix 2 contains a technical discussion of the sign of the wage effect.

The total effect of OPE, CPE and ATW is  $\frac{\partial \pi}{\partial n^j} < 0$  for marginal changes. Thus, increasing the number of workers in the market marginally is only worthwhile if the negative effect (CPE) is outweighed by a sufficient reduction in wages for inframarginal workers (WTW).

Several comments on the training equilibrium are worth making.

First, it is immediately clear that an equilibrium with positive amounts of training requires that for suitable levels of  $(g^i, g^j)$ , a marginal increase in own training has a positive effect on long-term payoffs for player  $i$ . In particular, the increase in gross profits from training (including the negative effect on competitors) must be at least as large as the increase in wage costs. This condition is known as the requirement of a *compressed wage structure* in models of general training (e.g., Acemoglu and Pischke 1999).

Second, the equal distribution of workers implied by (DRAW) is crucial for training to exist in equilibrium. Suppose that, as an extreme counterexample, one of the firms attracts all trained workers. Then, there can be no training: Both firms will have the same net product market profits, which amount to the gross profits of the firm without trained workers.<sup>19</sup> These profits are smaller than gross profits if neither firm trains. Therefore, in such cases the training equilibrium cannot exist.

Third, while Proposition 3 gives conditions where only equilibria with training exist, equilibria with and without training may also exist simultaneously. Using Propositions 2 and 4, this would require as a necessary condition that

$$\pi\left(\frac{g^*}{2}, \frac{g^*}{2}\right) - \frac{g^*}{2}v\left(\frac{g^*}{2}, g^*\right) \leq \pi(0, 0) + g^*I.$$

Finally, even though we do not explicitly treat the case of more than two firms, intuition suggests that, for given market size, training is less likely to arise in equilibrium for large numbers of firms. As argued above, such an equilibrium necessarily requires a sufficiently large effect of own training on wages. When there are many firms, however, the own effect on wages is likely to be small. Thus, again, it appears likely that increasing product market competition decreases training incentives.

### 4.3 Examples

In the following, we consider several examples, strengthening that training can arise only if competition is sufficiently soft.

#### 4.3.1 Price Competition with Homogeneous Firms

The first example is a general reformulation of the point from Section 3 that training cannot arise for intense competition. To this end, consider

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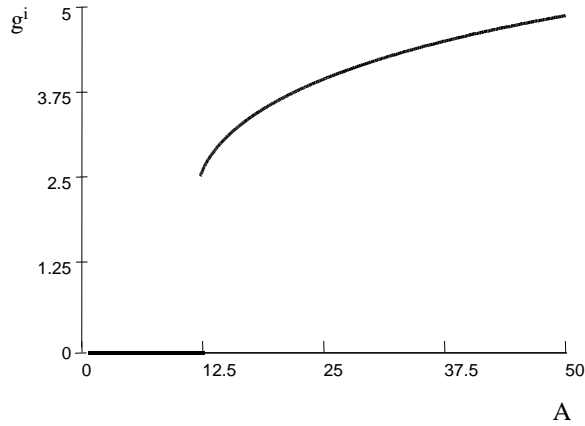
<sup>19</sup>If the firm that has no trained workers has lower net profits, it can imitate the firm that employs the workers by making slightly more attractive wage offers to all of the workers than the competitor.

two firms who can potentially train arbitrarily many workers. Suppose they compete à la Bertrand, that is, they sell homogeneous goods and choose prices simultaneously. Suppose that marginal costs are a decreasing functions of the number of trained workers employed in a firm.

Then, as in the intense-competition example in Section 3, if some workers have been trained, there must be an asymmetric equilibrium of the wage-bidding game in which both firms obtain the same net profit, namely zero. Thus, long-term payoffs would be negative in any equilibrium with training, and hence no training is the only equilibrium.

### 4.3.2 Price Competition with Heterogeneous Firms

As a numerical example, we consider the case of price competition of two firms producing imperfect substitutes, with demand functions  $D_i(p_i, p_j) = A - 10p_i + p_j$ , where  $0 \leq A \leq 30$ . 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. For simplicity, we suppose that each firm is restricted to training at most  $g^i = 4.15$  workers. Using the logic of Proposition 1, this assumption can be shown to guarantee that workers are distributed equally in the wage-bidding game. Finally, we set  $I = 0$  to investigate under which circumstances a training equilibrium would exist for sufficiently low training costs. Figure 3 plots equilibrium training levels as a function of the market size parameter. The outcome is in line with our general intuition: For low parameter values, no training takes place. Around  $A = 12.1$ , a second equilibrium emerges, with training level  $g^i \approx 2.45$ . As  $A$  increases further, training increases further.



Equilibrium Training Levels

Thus, as greater market size corresponds to softer competition, the idea that softer competition makes training more likely is confirmed once again. In terms of economic intuition, there are two reasons why this is so. First, increasing market size increases the benefits from cost reductions – a standard scale effect which is familiar from the analysis of cost-reducing innovations. Second, for a given number of trained workers an increasing market size will raise the wages for such workers. By training more workers, this wage effect can be alleviated.<sup>20</sup>

### 4.3.3 Monopolies

An interesting polar case is that the two firms are monopolies. Clearly, this corresponds to very soft competition. Thus, firms interact exclusively by competing for employees. Gross profits are thus a function of the number of own trained workers alone. With a slight abuse of notation, we therefore write the gross profits of a firm employing  $n^i$  trained workers as  $\pi(n^i)$  and thus  $v(n, G) = \pi(n^i)$ . Condition (DRAW) then requires that the function  $\pi(n^i)$  is concave. Similarly, condition (1) is violated for low  $I$  if  $\pi(n^i)$  is con-

<sup>20</sup>Whether wages increase or decrease when market size expands depends on parameters.



cave. Concavity of the profit function cannot be taken for granted, however. Suppose for definiteness that firms have linear demand  $a - p$  with  $a > 0$  and constant marginal costs  $c(n^i)$  which are decreasing in  $n^i$ . Then the profit function is convex in  $c$ , so that concavity of  $\pi$  requires marginal costs to be sufficiently concave in the number of trained workers. This condition must hold in addition to the requirement of soft competition to guarantee training.

## 5 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 mostly general in the sense of being 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 that is non-specific to the firm than Germany or Japan, at least at the initial stage of a worker's life (Blinder and Kruger 1996, Acemoglu and Pischke 1998).<sup>21</sup>

For simplicity, we suppose that for each industry under consideration, the German and the U.S. labor and product markets are completely separated. Each of the two corresponds to one set of parameters of the game. In terms of our model, there are thus two different types of explanations of the apparent differences between Germany and the U.S. 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 by Proposition 3, 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 train-

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<sup>21</sup>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.

ing equilibrium, while US firms are in the no-training equilibrium.

Regarding welfare, we have already seen in an example 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.<sup>22</sup>

In the former case, no government is necessary if firms coordinate on the payoff-dominant equilibrium. In the latter case, if firms coordinate on the no-training equilibrium, there could be a role for government to induce training. First, government intervention could bring industries into the training equilibrium. On the one hand, the state can offer complementary investments such as schooling facilities where costless classroom education is provided. Moreover, the government can regulate the curricula and demand that apprentices take standardized exams, as in Germany. 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. Which coordination mechanisms might be at work in Germany or in other countries is beyond the scope of this paper, but the preceding considerations raise the question of whether complementary activities or temporary support of the state could be useful to lead firms into the training equilibrium.

Perhaps the most important implication of our model is that increasing competitive intensity might destroy the training equilibrium. This suggests that apprenticeships will come under further pressure. More importantly, another crucial question arises: Can apprenticeships survive as firms are becoming more and more exposed to competitors from countries without

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<sup>22</sup>In all the examples we have investigated, training is socially desirable when the social welfare function is the unweighted sum of producer surplus, wages and consumer surplus.

such programs?

## 6 Conclusions and Extensions

In this paper, we provide a theory of industry-specific training. Our explanation of training does not rely on asymmetric information in the labor market. Instead, we require imperfect product market competition to generate equilibria with general training in a world 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. The role of product market competition comes from two sources here: a standard scale effect which is familiar from the analysis of cost-reducing innovations and a wage effect that is specific to models of training with turnover.

The arguments have been cast in a duopoly framework. They appear to hold more widely in an oligopolistic framework, but it is important to investigate how the number of firms in a market affects the likelihood of a training equilibrium. As discussed in Section 4.2, a plausible conjecture is that training becomes less likely as the number of firms increases, because competition becomes more intense. Indeed this is true in the Cournot case with linear demand.<sup>23</sup> For empirical applications we therefore hypothesize that training tends to be more likely in an industry if (i) concentration is high or competitive intensity is comparatively low, (ii) returns to training decrease sufficiently or (iii) product differentiation is sufficiently strong.

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<sup>23</sup>Details about such comparative exercises where the number of firms increases with and without adjustments of the market size are available upon request from the authors.

## 7 Appendices

### 7.1 Appendix 1: Proof of Proposition 1

**Proof.** For 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. 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 (DRAW). 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 (DRAW), 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.

To show that there is no equilibrium with  $n^i < n^j - 1$ , note that the willingness of firm  $i$  to pay for an additional worker is  $\pi(n^i + 1, G - n^i - 1) - \pi(n^i, G - n^i)$ , which by (DRAW) 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 ■

### 7.2 Appendix 2: The Wage Effect

**Proof.** 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  $\pi$  is concave as a function of  $n^i$  and convex as a function of  $n^j$ . Also, condition (DRAW), i.e., concavity

of  $\pi(n, G - n)$  as a function of  $n$  implies that  $\frac{\partial^2 \pi}{(\partial n^i)^2} + \frac{\partial^2 \pi}{(\partial n^j)^2} - 2 \frac{\partial^2 \pi}{\partial n^i \partial n^j} < 0$ . Unless  $\frac{\partial^2 \pi}{\partial n^i \partial n^j} - \frac{\partial^2 \pi}{(\partial n^j)^2}$  is very positive, therefore,<sup>24</sup>

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

and (WPTW) is therefore positive. ■

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<sup>24</sup>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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