A Product Market Theory of Training in Firms

Hans Gersbach* and Armin Schmutzler**[1]

*Alfred Weber Institut
Grabengasse 14
D-69117 Heidelberg
Germany
phone: ++49-6221-54 3173
fax: ++49-6221-54 3578

**Socioeconomic Institute
University of Zuerich
Bluemlisalpstr. 10
CH-8006 Zurich
Switzerland

phone: ++41-1-634 2270
fax: ++41-1-634 4987

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Abstract: We develop a product market theory explaining why firms invest in general training of their workers and managers. We consider a model where firms first decide whether to invest in general human capital, then make wage offers for the trained employees in the market and finally engage in imperfect product market competition. Multiple equilibria can emerge, with and without training. Firms train, if others do the same, because they would otherwise suffer a competitive disadvantage or have to pay high wages to poach workers. In the case of worker training, government intervention can be socially desirable to turn training into a focal equilibrium.

1 Introduction

Economists have long wondered why firms provide incentives for workers and managers to invest in productivity-enhancing general human capital. After all, these investments make the employees potentially more valuable for other employers. The famous arguments by Becker (1964) and Mincer (1974) suggest that firms should have no incentive to encourage general human capital acquisition, as the associated rents accrue fully to workers. However, these predictions seem at odds with reality (Acemoglu and Pischke 1998, Katz and Ziderman 1990, OECD 1999). In some countries such as e.g. Germany or Switzerland, firms voluntarily pay for apprenticeship providing workers with general skills. In addition, firms continually pay for on-the-job training of incumbent workers.[2]

Most explanations of why firms encourage general training investments rely on labor market imperfections caused by asymmetric information. Essentially, if present employers can observe ability (Acemoglu and Pischke 1998) or training (Katz and Ziderman 1990, Chang and Wang 1996) better than potential future employers, the latter will face a lemon's problem. As a result, it is difficult for the employee to sell herself on the job market. In this way, the original employer enjoys ex post informational monopsony power that creates incentives to finance general training.

In the following, we develop an alternative explanation of firm investments in general training which relies on oligopolistic competition in product markets rather than on asymmetric information in the labor market. In an oligopolistic setting, firms must consider the effects of their training decisions on competitors. At first glance, this lends additional support to the argument that firms have low incentives to finance general human capital acquisition:

[2]Several recent empirical studies show that a significant part of the training is general. Blundell et al. (1996), Goux and Marin (1997), Loewenstein and Spletzer (1998), Regner (1995, 1997) and Vilhuber (1997, 1998).

Not only does a firm lose the services of an employee who is poached by a competitor, but in addition the competitor is strengthened, which generally reduces the original employer's profits under oligopolistic competition. This makes the expected labor turnover particularly undesirable and forces firms to increase the wages of trained workers in order to deter them from leaving, thereby reducing training incentives in the first place. Indeed our first result is that with imperfect competition a firm's incentive to invest in general human capital when nobody else does are negative rather than zero, that is, Becker's original story applies with a vengeance. As firms suffer a competitive disadvantage when trained workers switch employers, general training allows workers to increase wage demands. No matter whether there is turnover or not, firms would thus be willing to pay for preventing workers from receiving such training.

The most important point of this paper is that the argument just described is only one side of the coin. While in our model there always exists an equilibrium where no firm trains its workers, for many parameter values another equilibrium exists where all firms provide general training. For this training equilibrium to exist, imperfect information is not needed, but product market competition must be imperfect since, otherwise, training investments cannot be recovered. The equilibrium arises as follows. If other firms offer general training to their workers as well, a firm in oligopolistic competition has an incentive to offer general training itself. If it does not, it either faces a competitive disadvantage or it must offer large wages to poach workers from competitors. We will show that even in the simplest case with two firms competing in quantities in a homogenous product market, both the no-training and the training equilibrium exist as long as the market is sufficiently large. In addition, the training equilibrium is better than the no-training equilibrium in terms of social welfare.

Having established the existence and consequences of multiple equilibria, we discuss which institutional coordination mechanisms can move firms into the training equilibrium: industry associations, wage bargaining between industry associations and unions and government intervention. 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 analysis can explain why firms provide general worker training. Application to *manager* training requires extensions. A potential difference between general training of workers and managers is that the latter may lead to long-lasting impacts within a firm. For instance, if a manager uses her increasing knowledge about organizational restructuring to implement cost-reducing changes, these changes may well survive her departure to a competitor. If she leaves, both firms will end up with low costs. As a result, equilibria without training are less likely, so that there is a smaller role for institutions and policy.

While our theory of training focuses on product market imperfections, it shares the feature of multiple equilibria with the models of Katz and Ziderman (1990), Chang and Wang (1995,96), Abe (1994), Prendergast (1992), Glaeser (1992), Acemoglu (1997) and Acemoglu and Pischke (1998) which rely on labor market imperfections instead. As argued by Acemoglu and Pischke (1996), all existing models in which firms pay for general training are driven by such imperfections. These authors also show that such models require the rents to be increasing in the skill level of workers. In our theory, firms invest in training to reduce rents of trained workers and thus the wage costs associated with obtaining or retaining human capital. In this sense, the product market approach provides a genuinely new way of thinking about firm training.

In the following, we spell out these arguments in more detail. In section

2, we introduce a model of human capital investment in duopolistic markets, which encompasses the training of managers and workers as special cases. Section 3 shows how multiple equilibria, both with and without training, can arise when human capital is completely embodied in the person of the employee, which is likely in the case of workers. Section 4 shows how the argument has to be modified in the polar case that human capital acquisition leaves its marks within the firm, as we would expect for managers. Section 5 extends the analysis from the case that each firm employs at most one worker to arbitrary numbers of workers. Section 6 concludes.

2 The Model

In this section we develop a model which can encompass general training both of managers and workers. We shall first sketch our basic model, before describing it in detail.

There are two firms. To make arguments as transparent as possible, we use the heroic assumption that each firm employs only one employee; this will be relaxed in section 5. Through training, this employee can acquire general human capital. Having employees with general human capital is beneficial for the present employer; it could for instance help to reduce production costs. On the other hand, investing in training is costly. We assume that the entire cost of human capital acquisition is borne by the firm. After both firms have chosen how much to invest in training, employees have the opportunity to change firms. Their decisions depend on the wages offered by the current employer and the potential future employer. After the employees have chosen firms, product market competition takes place. The cost structure of the firms depends on the original human capital investment decision and on whether or not the employee switches firms: if the employee switches firms, the competitor will be able to reduce costs.

2.1 Assumptions

In more detail, the structure of the model is as follows. In period 1, firms $i = 1, 2$ simultaneously choose their general human capital investment levels g^i. For simplicity we suppose that g^i is either 0 or 1.[3] The investment cost is $I > 0$. At the beginning of period 2, firm i can make wage offers $w_{ii}(g^i, g^j)$ for their own worker and $w_{ij}(g^i, g^j)$ for the competitor's worker who has received training g^j. Here "wages" should be interpreted broadly, including any type of non-monetary benefits such as pleasant working environments, fringe benefits and flexible working hours as well as monetary payments. We normalize wages of non-trained workers to zero. After having obtained the wage offers, the employee accepts the higher offer.[4] In period 3, product market competition takes place. We model this competition in reduced form, with product market profits taking the form $\pi^i(y^i, y^j)$, where y^i and y^j are one-dimensional state variables, interpretable as cumulated cost reduction or as product quality levels.

The link between the first two periods and product market competition arises because the state of a firm depends on the training decisions of both firms as well as on the labor turnover patterns. How training decisions and turnover patterns influence states depends, i.a., on whether the employees are workers or managers. We shall illustrate this for both cases shortly, after introducing a unified framework to deal with both cases. For now, we suppose that states are uniquely determined by training and turnover. Accordingly we write $y^i_{t^i}(g^i, g^j)$ for the state of firm i if its general training level is g^i, the competitor's level is g^j and turnover patterns are described by $t^i \in \{n, in, out, m\}$, where

[3] Section 5 goes a long way towards showing how the analysis might be generalized when the training decision is not of the 0-1 type.

[4] As a tie-breaking rule, we use the convention that the employee stays in the old firm if $w_{ii} = w_{ji}$.

- $t^i = n$ if there is no turnover,
- $t^i = in$ when only firm i attracts the other firm's employee,
- $t^i = out$ when only firm j attracts the other firm's employee,
- $t^i = m$ when there is mutual poaching.

We always assume that non-trained employees stay with their firms and, as a normalization, that they earn zero wages. State levels of firm i are summarized in the following table. Here, different rows stand for different training decisions, different columns for different turnover patterns.

$\frac{Turnover}{Training}$	non	out	in	mutual
0,0	$y_n^i(0,0)$	-	-	-
1,0	$y_n^i(1,0)$	$y_{out}^i(1,0)$	-	-
0,1	$y_n^i(0,1)$	-	$y_{in}^i(0,1)$	-
1,1	$y_n^i(1,1)$	$y_{out}^i(1,1)$	$y_{in}^i(1,1)$	$y_m^i(1,1)$

For instance, $y_n^i(1,0)$ is the state of firm i if its level of general training is 1, whereas the competitor's level is 0, and there is no turnover. $y_m^i(1,1)$ may be higher than $y_n^i(1,1)$, when there are complementarities between the human capital investment in the two firms. We assume that firms are identical in the sense that, for every t, the functional form of $y_{t^i}^i$ is independent of of the firm label, i.e. for $t_i = t_{j,}$, we obtain $y_{t^i}^i\left(\widetilde{g}, \widetilde{\widetilde{g}}\right) = y_{t^j}^j\left(\widetilde{g}, \widetilde{\widetilde{g}}\right)$ for $i \neq j$ and any pair of investment levels $\widetilde{g}, \widetilde{\widetilde{g}}$. Thus we often drop indices and write $y_t\left(g^i, g^j\right)$ to denote the state of a firm that has chosen g^i, while the competitor has chosen g^j. We now show how the function y_t reflects our two special cases: worker training and manager training.

2.1.1 Example 1: Worker Training

As a first polar case, we consider worker training, characterized as follows. We assume that if an employee leaves the firm, the original employer looses all the benefits generated by the original human capital investment - the employee is gone without having left any traces. This is the same assumption as in the theories of firm training based on labor market imperfections. In addition, we assume that training a worker and hiring a trained worker are perfect substitutes. This assumption differs from the training literature which argues that own workers and competitor's workers are imperfect substitutes, because the ability of the own worker is known better. We use perfect substitutability to express the generality of human capital in its starkest form, and we shall show later on that, inspite of this assumption, general training can arise in equilibrium. Given this set-up, the state of the firm only depends on the number of trained workers who are currently in the firm. This is most likely to be a good approximation when the firm invests in general training of workers such as in the German apprenticeship programs. For manager training, this assumption is less palatable. We shall deal with this case separately below. In addition, we abstract from complementarities between workers, that is, we assume $y_{in}(1,1) = y_n(1,1)$. This is a strong assumption, as it implies that having two educated workers is no better than having one educated worker. We maintain it only to simplify the presentation of our main argument. In section 5, we generalize our story to the case where additional workers do have an additional value. Normalizing $y_n(0,0) = 0$ and $y_m(1,1) = 1$, we thus invoke the following assumption.

Assumption W:

(i) $y_{out}(1,0) = y_n(0,0) = y_{out}(1,1) = y_n(0,1) = 0$.

(ii) $y_m(1,1) = y_n(1,0) = y_n(1,1) = y_{in}(1,1) = y_{in}(0,1) = 1$.

2.1.2 Example 2: Manager Training

Section 2.1.1 described the polar case that an employee has left a firm, the fruits of general human capital investment are gone without traces. We now consider the case that the improvements generated by former employees remain visible within the firm. This is most likely to apply for managers at low, middle or high levels. If a trained manager has implemented organizational changes with positive effects on firm performance, these changes are likely to survive the manager's departure. Hence, the only problem if a manager leaves a firm is that the competitor improves its state as well, which induces a profit reduction for the original employer under reasonable assumptions (see section 2.2).

To make the point clearly, we move to the polar case that the original employer retains *all* the benefits associated with the human capital investment when the employee leaves. This is surely not always realistic but is useful to illustrate the consequences of moving to the polar case compared with section 2.1.1.

Assumption M1: $y_{out}(1, g^j) = y_n(1, g^j) = 1$.

On the other hand, we also assume, as above, that the new employer benefits fully from the human capital investment, more precisely, that poaching a trained manager is as good as training a manager oneself.

Assumption M2: $y_{in}(0, 1) = y_n(1, 0) = y_n(1, 1) = 1$.

Finally, we allow for complementarities between training of manager in different firms.

Assumption M3: $y_{in}(1, 1) = y_m(1, 1) = (1 + \beta) \cdot y_n(1, 1) = 1+ \beta$ with $\beta \geq 0$.

Hence, compared with a situation with no turnover, both firms may benefit from the "fresh blood" effect of having a new manager with outside experience in the organization. Finally, we normalize $y_n(0, g^j) = 0$ as before.

2.2 The Product Market

As to the product market, we make the following assumptions. First, we suppose that for each vector of states $\mathbf{y} = (y_t^1, y_t^2)$ there exists a unique product market equilibrium with resulting product market *profits* $\pi^i\left(y_t^i, y_t^j\right)$.[5] Again, we assume that firms are identical ex ante and thus profit functions are the same for both firms.[6] For a firm with product market profits $\pi^i(y_t^i, y_t^j)$, we introduce the following derived functions.

- The *product market profit for symmetric firms, i.e., for firms which have the same state variable*: $\widehat{\pi}^i(y_t) = \pi^i(y_t, y_t)$.
- *Second-period payoff*: $\Pi^i(y_t^i, y_t^j) = \pi^i(y_t^i, y_t^j) - wages$.
- *Total payoff*: $\Pi^i(y_t^i, y_t^j) - g^i \cdot I$

Also, we assume that profits are increasing in the own state and decreasing in the competitor's state.[7] In addition, we impose the slightly more restrictive assumption that profits increase if, starting from a symmetric situation, both states increase by the same amount. We thus make the following assumption throughout the paper.

Assumption 1: $\frac{\partial \pi^i}{\partial y_t^i} \geq 0$; $\frac{\partial \pi^i}{\partial y_t^j} \leq 0$, $\frac{\partial \hat{\pi}^i}{\partial y_t} > 0$.

2.3 Some simple results

With these assumptions on product-market competition in place, we now proceed to characterize equilibrium behavior. A subgame perfect equilibrium of the game consists of strategies $(g^i, w_{ii}(g^i, g^j), w_{ij}(g^i, g^j))$ for $i = 1, 2; j \neq i$.[8]

[5] These are gross profits from which the wages of trained employee are not yet subtracted. From the point of view of period 3, these wage costs are fixed costs.

[6] More formally, we assume that profit fuctions are exchangeable, that is, if $T : \Re^2 \longrightarrow \Re^2$ is a map transposing the two elements, $\pi^j\left(T\left(y^i, y^j\right)\right) = \pi^i\left(y^i, y^j\right)$.

[7] While this property usually holds for cost reductions, it is not satisfied in all models of quality competition: it holds in the Dixit (1979) model with heterogeneous goods, but it is not satisfied in the models of Ronnen (1991), Shaked and Sutton (1982).

[8] Strictly speaking, there is a choice of product market strategies in the third period, which we ignore as they enter the reduced form product market profits.

In lemmas 2 and 3, it will turn out that there is either a unique second-period equilibrium for each vector (g^i, g^j), or that, whenever the equilibrium is not unique, second-period payoffs are identical in the different equilibria. Thus we write $\widetilde{\Pi}^i(g^i, g^j)$ for the second-period payoff in any such equilibrium. We start with a simple characterization of the subgame perfect equilibrium (SPE) that treats the second period as a black box. This box will be opened in subsequent sections.

Lemma 1 *(a)* $(0,0)$ *is an SPE (deemed the* ***no-training equilibrium)*** *if and only if, for* $i = 1,2$*:*[9]

$$\widetilde{\Pi}^i(0,0) \geq \widetilde{\Pi}^i(1,0) - I.$$

(b) $(1,1)$ *is an SPE (deemed the* ***training equilibrium****) if and only if, for* $i = 1,2$*:*

$$\widetilde{\Pi}^i(1,1) - I \geq \widetilde{\Pi}^i(0,1).$$

Part (a) merely states the obvious fact that for an equilibrium with no training to exist, the increase in second-period payoffs (net of wages) resulting from training must not outweigh the investment costs. Similarly (b) states that for both firms to invest, the losses in second period payoffs (net of wages) must not outweigh the savings in investment costs.

The next two results are complementary to lemma 1. They characterize the pure Nash equilibria of the second-period turnover game. First we consider the case that only one firm has invested.

Lemma 2 [10]

(a) Suppose $g_i = 1, g_j = 0$*. Then turnover takes place in equilibrium if and*

[9] Here and in the following,we use the terminology "(g^1, g^2) is an SPE" if some SPE exists such that training levels are (g^1, g^2) for the SPE strategies.

[10] The statement of this result uses the above-mentioned convention that indices may be dropped in product market profits by exchangeability. Without the exchangeability assumption, the lemma can be generalized in a straightforward fashion.

only if

$$\pi(y_n(1,0), y_n(0,1)) - \pi(y_{out}(1,0), y_{in}(0,1)) \leq \tag{1}$$
$$\pi(y_{in}(0,1), y_{out}(1,0)) - \pi(y_n(0,1), y_n(1,0)).$$

Wage offers are $w_{ii} = w_{ji} = \pi(y_n(1,0), y_n(0,1)) - \pi(y_{out}(1,0), y_{in}(0,1))$. *Second period payoffs are*

$$\begin{aligned}\widetilde{\Pi}^i(1,0) &= \pi(y_{out}(1,0), y_{in}(0,1)) \\ \widetilde{\Pi}^j(0,1) &= \pi(y_{in}(0,1), y_{out}(1,0)) \\ &\quad - \pi(y_n(1,0), y_n(0,1)) + \pi(y_{out}(1,0), y_{in}(0,1)).\end{aligned} \tag{2}$$

(b) If (1) and (2) holds with sign reversed, there is no turnover. Wages are

$$w_{ii} = w_{ji} = \pi(y_{in}(0,1), y_{out}(1,0)) - \pi(y_n(0,1), y_n(1,0)).$$

Second period payoffs are

$$\begin{aligned}\widetilde{\Pi}^i(1,0) &= \pi(y_n(1,0), y_n(0,1)) - \pi(y_{in}(0,1), y_{out}(1,0)) + \pi(y_n(0,1), y_n(1,0)) \\ \widetilde{\Pi}^j(0,1) &= \pi(y_n(0,1), y_n(1,0)).\end{aligned}$$

The proof follows from a simple check of best-response conditions. Intuitively, for turnover to take place, the employer must have less to lose from letting the worker go than the competitor stands to gain from hiring the employee. Wages are then bid up to the valuation of the trained employee by the former employer. For the case without turnover, the result follows by reversing this argument.

The next result describes the turnover game when both firms have invested in human capital. We first assume that, for symmetric firms, states are not lower when there is mutual poaching than when there is no turnover.

Assumption 2: $y_m(1,1) \geq y_n(1,1)$.

Together with assumption 1 this immediately implies

$$\pi(y_m(1,1), y_m(1,1)) \geq \pi(y_n(1,1), y_n(1,1)). \tag{3}$$

Using this assumption, the following result holds.

Lemma 3 *Suppose assumptions 1 and 2 hold. In addition, suppose no weakly dominated strategies are played.*
(a) Suppose $g_i = 1, g_j = 1$. *Then there exists an equilibrium with mutual poaching if and only if*

$$\begin{aligned} &\pi(y_m(1,1), y_m(1,1)) - \pi(y_{out}(1,1), y_{in}(1,1)) \geq \\ &\pi(y_{in}(1,1), y_{out}(1,1)) - \pi(y_m(1,1), y_m(1,1)). \end{aligned} \tag{4}$$

Wages in this case are given uniquely as
$w_{ii} = w_{ij} = \pi(y_{in}(1,1), y_{out}(1,1) - \pi(y_m(1,1), y_m(1,1)).$

Second period payoffs are

$$\widetilde{\Pi}^i(1,1) = \widetilde{\Pi}^j(1,1) = 2\pi(y_m(1,1), y_m(1,1)) - \pi(y_{in}(1,1), y_{out}(1,1)).$$

(b) If (4) holds with signs reversed, there is asymmetric poaching, that is one of the two firms (i) hires the other firm's worker, but keeps its own. There may be more than one equilibrium in this case, that is, individual wage offers are not uniquely determined, but the sum of wages is always

$$w_{ii} + w_{ij} = \pi(y_{in}(1,1), y_{out}(1,1)) - \pi(y_{out}(1,1), y_{in}(1,1)).$$

Second period payoffs are given uniquely as

$$\widetilde{\Pi}^i = \widetilde{\Pi}^j = \pi(y_{out}(1,1), y_{in}(1,1)).$$

(c) There is no equilibrium without turnover, except possibly in the boundary case that

$$\pi(y_m(1,1), y_m(1,1)) = \pi(y_n(1,1), y_n(1,1))$$

If there is an equilibrium without turnover in this boundary case, wages and second period payoffs are the same as in the case of mutual poaching.

We now combine lemma 1 with lemmas 2 and 3 to express the first-period equilibrium as a function of parameters. Before, we introduce some notation to characterize two polar examples of parameter regimes.

Definition 4

(*i*) *Suppose that product market profits are such that in the second period there is turnover if only one firm has invested and mutual poaching if both firms have invested, that is, conditions (1) and (4) hold. Then, firms are said to operate in the* ***soft competition regime****.*

(*ii*) *Suppose that product market profits are such that in the second period there is no turnover if only one firm has invested and asymmetric poaching if both firms have invested, that is, conditions (1) and (4) hold with signs reversed. Then, firms are said to operate in the* ***tough competition regime.***[11]

The justification of the terms soft and tough competition regime will become more apparent later: roughly speaking, conditions(1) and (4) hold with reverse signs for Bertrand competition, which is seen as tough competition. Combining lemmas 1-3 immediately gives the following result:

[11] The two parameter regimes are not necessarily fully exhaustive. Depending on the functional relation between general human capital investment, turnover and states and on other parameters, it may happen that there is no turnover if one firm has invested and symmetric turnover if both have invested. Similarly, there may be turnover if one firm has invested and asymmetric turnover if both firms have invested.

Proposition 5 *a: Suppose parameters are in the soft competition regime. Then*
(i) $(0,0)$ *is an SPE if*

$$\pi(y_n(0,0), y_n(0,0)) \geq \pi(y_{out}(1,0), y_{in}(0,1)) - I. \tag{5}$$

(ii) $(1,1)$ *is an SPE if*

$$2\pi(y_m(1,1), y_m(1,1)) - \pi(y_{in}(1,1), y_{out}(1,1)) - I \geq \tag{6}$$
$$\pi(y_{in}(0,1), y_{out}(1,0)) - \pi\left(y_n\left(1,0\right), y_n\left(0,1\right)\right) + \pi\left(y_{out}\left(1,0\right), y_{in}\left(0,1\right)\right)$$

(iii) $(1,0)$ *is an SPE if (5) and (6) hold with signs reversed.*

b: Suppose parameters are in the tough competition regime. Then
(i) $(0,0)$ *is a SPE if, in addition,*

$$\pi(y_n(0,0), y_n(0,0)) \geq \tag{7}$$
$$\pi(y_n(1,0), y_n(0,1)) - \pi(y_{in}(0,1), y_{out}(1,0)) + \pi(y_n(0,1), y_n(1,0)) - I.$$

(ii) $(1,1)$ *is a SPE if, in addition,*

$$\pi(y_{out}(1,1), y_{in}(1,1)) - I \geq \pi(y_n(0,1), y_n(1,0)). \tag{8}$$

(iii) $(1,0)$ *is an SPE if (7) and (8) hold with signs reversed.*

In the next two sections, we apply proposition 5 to worker and manager training, respectively, by specifying how the state variables are influenced by turnover. To illustrate the intuition, consider soft competition. The left hand side of (3) is the total payoff when neither firm invests. The right hand side gives the total payoff from deviation to (1,0), bearing in mind that, with soft competition, there will be turnover so that the investing firm has state $y_{out}(1,0)$, and the competitor has state $y_{in}(0,1)$. To understand the corresponding condition for the training equilibrium, note that, with soft competition, there is mutual turnover if both firms have invested, yielding product market profits $\pi(y_m(1,1), y_m(1,1))$, from which wages $\pi(y_{in}(1,1), y_{out}(1,1) - \pi(y_m(1,1), y_m(1,1))$ and investment costs have to be subtracted to obtain total equilibrium payoffs on the l.h.s. of (4). The r.h.s. gives equilibrium payoffs if one does not invest, after subtracting the costs of poaching the competitor's employee, which are $\pi(y_n(1,0), y_n(0,1)) - \pi(y_{out}(1,0), y_{in}(0,1))$ by lemma 2. Tough competition has similar interpretation.

3 Application 1: Worker Training

We now use proposition 5 to analyze whether training is likely for employees whose knowledge is gone without traces when they leave the firm, as is to be expected for workers. In section 3.1, we derive equilibrium conditions for this case, which we apply to the linear Cournot model in section 3.2. Section 3.3 provides a welfare analysis. Section 3.4 links our results to real-world policy discussions.

3.1 Equilibrium Conditions

We now analyze the equilibria in the case of worker training, that is, in the case that assumption W holds. To apply proposition 5, we need to know whether we are in the soft or in the tough competition regime. First note that assumption W implies

$$\pi(y_n(1,0), y_n(0,1)) - \pi(y_{out}(1,0), y_{in}(0,1)) = \\ \pi(y_{in}(0,1), y_{out}(1,0)) - \pi(y_n(0,1), y_n(1,0)). \quad (9)$$

Hence, (1) holds with equality. Thus according to lemma 2, if only one firm has invested in training, both equilibria with and without turnover are feasible; but the wages for trained employees are $\pi(1,0) - \pi(0,1)$ in both cases and hence second period payoffs are the same, namely:

$$\widetilde{\Pi}^i = \widetilde{\Pi}^j = \pi(y_{out}(1,0), y_{in}(0,1)) = \pi(y_n(0,1), y_n(1,0)) = \pi(0,1).$$

The wage offer illustrates the problem of firms that want to avoid a competitive disadvantage when one firm has invested in training. Both firms share the same willingness to pay for retaining or obtaining the trained worker, namely $\pi(1,0) - \pi(0,1)$. Essentially, the worker extracts all the difference between the profits of a firm that has a trained worker and the profits of a firm that has none. Another consequence of assumption W is that, as (1) is satisfied with equality, whether there is soft or tough competition depends entirely on inequality (4): Soft competition occurs if and only if

$$2\pi(1,1) - \pi(0,1) - \pi(1,0) \geq 0. \quad (10)$$

If the inequality holds with "smaller or equal", there is tough competition. Accordingly, applying Proposition 5, we obtain:

Proposition 6 *Suppose assumption W holds. Then*
(i) $(0,0)$ *is always an SPE. Second period payoffs are* $\pi(0,0)$*.*
(ii) $(1,0)$ *is never an SPE.*
(iii) $(1,1)$ *is never an SPE under tough competition.*
(iv) $(1,1)$ *is an SPE under soft competition if and only if*

$$2\pi(1,1) - \pi(0,1) - \pi(1,0) \geq I. \quad (11)$$

In this equilibrium, no turnover occurs. Wages are $\pi(1,0)-\pi(1,1)$ *and total payoffs amount to* $2\pi(1,1)-\pi(1,0)-I$*.*

Proof. (i) follows directly from proposition 5 and assumption W. (ii) follows because 5 with reverse sign is $\pi(0,0) \leq \pi(0,1)-I$, which is incompatible with assumption 1. As to (iii), proposition 5 shows that under tough competition an equilibrium $(1,1)$ would require

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

This is inconsistent with $I > 0$. Concerning (iv), recall that soft competition implies $2\pi(1,1)-\pi(0,1)-\pi(1,0) \geq 0$. As this implies soft competition, proposition 5 shows that the equilibrium conditions in (iv) are those stated above. ■

Proposition 6 and its proof have two major implications. First, in one respect Becker's argument that firms have no incentives to invest in general human capital is strengthened. Not only is there an equilibrium without general human capital investment for arbitrary parameter values, but things are even worse than in Becker's world. If, as assumption 1 requires, product market profits depend negatively on the competitor's state, incentives to invest are negative rather than zero: even if I were equal to zero, a firm would be *strictly* better off not investing at all. A firm that invests in human capital makes itself vulnerable to the threat that its worker leaves the firm, thus hurting the firm not only by increasing its own costs, but also by decreasing the competitor's cost. It is immaterial whether the worker actually carries out the threat: if she does, the original employer will lose $\pi(1,0)-\pi(0,1)$, if not, she will enjoy a wage payment of the same amount. As a result, firms would be willing to pay a positive amount of money to prevent employees from acquiring human capital even when there are no training costs.

Second, if product market competition is soft, there is another equilibrium where both firms invest in general training. The intuition why firms are willing to invest is as follows. With soft competition, starting from a situation where both firms have invested, neither would gain anything from poaching the competitor's worker since both firms already have the human capital in house.[12] To keep the workers (or to hire the competitor's worker if the own worker leaves), firms need to offer wages $\pi(1,0) - \pi(1,1)$. These wages are smaller than in the case where only one firm invests, because the outside options of workers are less attractive. Second period payoffs are $2\pi(1,1) - \pi(1,0)$. Giving up training investment unilaterally yields second period payoffs $\pi(0,1)$, independently of whether the trained worker will be hired, because hiring is so costly. Overall, the fear of increasing future wage costs by not investing in training can motivate firms to invest in human capital.

3.2 An example: The linear Cournot case

The training equilibrium is a non-pathological case. This is easily demonstrated in the simple case of quantity competition, assuming that the firms produce homogeneous goods, with market demand $x = a - p$; where x is output, p is price and a is a positive constant. We specify the meaning of the state variable y as follows. Suppose both firms have an initial marginal cost level c_o. The state y^i describes the extent to which marginal costs of firm i are below c_o, that is $\pi^i\left(y^i, y^j\right)$ is the profit of a firm if its own marginal costs are $c_o - y^i\Delta$ and the competitor's costs are $c_0 - y^j\Delta$, where Δ is some positive number.

Application of proposition 6 shows that in this setting an equilibrium with

[12] The strong assumption that the second worker gives no additional benefits will be relaxed in section 5, where we shall show that a similar result holds when the profit from losing one worker is greater than the gain from getting another worker.

training may arise, provided that competition is sufficiently soft in the sense that the initial market size $(a - c_o)$ is large enough relative to investment costs and potential cost reduction. More precisely, use the standard result that, if firm i has marginal costs c_i, its profits are $\frac{(a-2c_i+c_j)^2}{9}$ for $i = 1, 2$, $j \neq i$. Applying parts (iii) and (iv) of proposition 6 immediately yields the following result.

Corollary 7 *: In the linear Cournot example,* $(1, 1)$ *is an equilibrium if and only if* $2\,(a - c_o)\,\Delta - 3\Delta^2 \geq 9I$.

Note, however, that, with the same linear demand function and Bertrand rather than Cournot competition $(1, 1)$ cannot be an equilibrium, as a straightforward application of proposition 6 shows. This is unsurprising since Bertrand competition is essentially perfect competition and firms operate in the tough competition regime. This reinforces the idea that the strength of competition determines whether a training equilibrium might survive.

3.3 Welfare Analysis

In this section, we perform welfare comparisons between equilibria with and without training. We start by looking at firm profits. It is possible that the training equilibrium is ranked higher than the no-training equilibrium in terms of total payoffs for firms. Essentially, this requires product market competition to be sufficiently soft.

Proposition 8 *Suppose that assumption W holds and that training and no-training equilibria coexist, i.e.,*

$$2\pi(1, 1) - \pi(1, 0) - \pi(0, 1) \geq I. \tag{13}$$

Then, the training equilibrium is better for firms if and only if

$$2\pi(1, 1) - \pi(1, 0) - \pi(0, 0) \geq I. \tag{14}$$

Straightforward derivations show that condition (14) is never satisfied in the linear Cournot case.[13]

In the next step we compare aggregate welfare in equilibria with and without training. Aggregate welfare is defined as the sum of total payoffs of firms, wages and consumer surplus. Suppose that firms compete in a market with homogeneous products and demand function $D(p)$. We denote by $p^*(g^1, g^2)$ the equilibrium prices depending on training levels. In the training equilibrium, the sum of firms' total payoffs, wages and consumer surplus is given by

$$2\pi(1,1) - 2I + \int\limits_{p*(1,1)}^{\infty} D(p)dp. \tag{15}$$

In the no-training equilibrium aggregate welfare is given by

$$2\pi(0,0) + \int\limits_{p*(0,0)}^{\infty} D(p)dp. \tag{16}$$

Therefore, we obtain:

Proposition 9 *Suppose that training and no-training equilibria coexist. Then aggregate welfare is higher in the training equilibrium if and only if*

$$2\pi(1,1) - 2\pi(0,0) + \int\limits_{p*(1,1)}^{p*(0,0)} D(p)dp > 2I. \tag{17}$$

It is readily verified for the linear Cournot case that, if it exists, the training equilibrium dominates the no-training equilibrium in terms of welfare.

[13] Obviously, condition (14) may hold in other examples, for instance when products are sufficiently differentiated, so that each firm is essentially an monopolist and hence $\pi(1,1) \approx \pi(1,0)$.

By combining proposition 8 and 9 for the linear Cournot case, we observe that firms are better off in the no-training equilibrium, but welfare is higher in the training equilibrium. If firms use the Pareto selection criterion to coordinate themselves on no-training, there could thus be a role for government policy to reach the training equilibrium which will be now be discussed.

3.4 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 in the same industry. Nevertheless, firms bear part of the training costs. In contrast, the U.S. economy appears to generate less general training than Germany or Japan, at least at the initial stage of a worker's life (Blinder and Kruger 1996, Acemoglu and Pischke 1998).[14] Our analysis could provide potential explanations of these differences. An obvious interpretation is that Germany and the U.S. can be thought of as being in different equilibria; i.e., German industries are in the training equilibrium and U.S. industries are in the no-training equilibrium. Why should these differences arise? In particular, what are the mechanisms explaining why industries in a country may coordinate on the training equilibrium? Potentially, there are at least three such mechanisms, which work by slightly modifying the payoff structure or by turning training into a focal equilibrium.

First, wage setting institutions may promote the training equilibrium. In Germany, large employer associations and labor unions negotiate about wages and working conditions. Establishing curricula and other formal procedures

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

in connection with negotiations could enhance the chances of settling in the training equilibrium.

Second, governmental 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.

Third, in those cases where the training equilibrium yields higher profits, industry associations themselves may facilitate coordination on a training equilibrium. For instance, by offering special courses for apprentices, paid from the associations' budgets, the association may be able to promote participation in training programs.

Which coordination mechanisms might be at work in Germany or in other countries with similar programs is beyond the scope of this paper, but the preceding considerations raise the question whether complementary activities or temporary support of the state could be useful to lead firms into the training equilibrium. As an example we have seen that government intervention can be justified in the linear Cournot case.

Another implication of our model is that increasing competitive intensity might destroy the training equilibrium. This suggests that the German apprenticeship might come under serious pressure when competition in manufacturing increases further. More importantly, another important question arises: can the German apprenticeship survive as firms are becoming more and more exposed to competitors without such programs?

4 Application 2: Manager training

In this section, we use proposition 5 to examine manager training. We show that when the training or no-training equilibria exist, they tend to be essentially unique, so that the policy problems described in the last section do not apply.

4.1 Set-up and equilibrium conditions

First note that under assumptions M1-M3 equations (1) and (4) characterizing the soft competition regime read:

$$\begin{aligned}\pi(1,0)-\pi(1,1) &\leq \pi(1,1)-\pi(0,1);\\ \pi(1+\beta,1+\beta)-\pi(1,1+\beta) &\geq \pi(1+\beta,1)-\pi(1+\beta,1+\beta)\end{aligned}$$

Hence Proposition 5 immediately implies the next result.

Proposition 10 *Under assumptions M1-M3, the equilibrium structure is given as follows.*[15]
(i) In the soft competition regime, $(0,0)$ *is a SPE if and only if*

$$\pi(0,0)\geq\pi(1,1)-I$$

$(1,1)$ *is a SPE if and only if*

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

[15] We confine ourselves to symmetric equilibria. For parameter constellations not covered in the following, there also are two asymmetric equilibria, each with one of the two firms investing.

(ii) Under tough competition,
$(0,0)$ *is a SPE if and only if*

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

$(1,1)$ *is an SPE if and only if*

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

One obvious difference between manager and worker training is an immediate consequence of the assumption that managerial knowledge is implemented in the organization, while worker knowledge is not.

Corollary 11 *: The parameter range for which no training is an equilibrium is smaller in the managerial case than in the worker case.*

The reason for this result is that incentives to deviate from the no-training equilibrium are $\pi(0,1) - I$ in the worker case, whereas they are $\pi(1,1) - I$ or $\pi(1,0) - \pi(1,1) + \pi(0,1) - I$ in the managerial case, according to whether competition is soft or tough.

In this sense, firms have larger incentives to train managers than workers. Hence, the policy issues arising for worker training appear to be less serious in the context of manager training.

5 An extension: Arbitrary numbers of workers.

So far, we have confined ourselves to the patently unrealistic case that each firm can train at most one worker, or more precisely, to the case that only one trained worker is valuable for the firm. As we now show, allowing for the possibility of increasing the state by training additional workers does not change the basic result that firms may have incentives to invest in general training. In period 1, each firm decides how many workers to train. Training costs are linear in the number g^i of trained workers, training any worker costs I units. In period 2, each firm makes wage offers to all of its workers and to all of the competitor's workers. As before, workers accept the higher offer, and stay with their initial employer if wage offers are identical.

We use the simplifying assumption that the state of each firm depends only on the number n^i of educated workers it employs at the end of the poaching game, which is greater or smaller than g^i if firm poaches workers from the competitor, equal to g^i if there is no poaching, and smaller if firm j poaches workers from firm i. Assuming that the functional form of the state as a function of the number of employed workers is the same for both firms, we write $y^i = y(n^i)$, and we define $\widetilde{\pi}(n^i, 2N) = \pi(y(n^i), y(2N - n^i))$, where $2N$ is the total number of educated workers, which is assumed to be even for simplicity.

Finally, we invoke an assumption on the functional form of $\widetilde{\pi}$.

Assumption 3: $\widetilde{\pi}$ is strictly concave in n^i. This assumption requires some interpretation. Straightforward calculations show that[16]

$$\begin{aligned}\frac{\partial^2\widetilde{\pi}}{\partial(n^i)^2} &= \pi_1\frac{\partial^2 y}{(\partial n^i)^2} + \pi_{11}\left(\frac{\partial y}{\partial n^i}\right)^2 - \pi_{12}\left(\frac{\partial y}{\partial n^i}\right)^2 - \\ &\quad \pi_2\frac{\partial^2 y}{\partial(n^i)^2} - \pi_{21}\left(\frac{\partial y}{\partial n^i}\right)^2 + \pi_{22}\left(\frac{\partial y}{\partial n^i}\right)^2, \qquad (18)\end{aligned}$$

evaluated at the appropriate arguments.

Whether particular oligopoly models satisfy the concavity assumption depends crucially on $\frac{\partial^2 y}{\partial(n_i)^2}$. For instance, if $\frac{\partial^2 y}{\partial(n_i)^2}$ is sufficiently negative, $\widetilde{\pi}$ is concave.[17]

[16]As usual, subscripts stand for partial derivatives in the following.

[17]However, Athey and Schmutzler (1999), have shown that π_{11} and π_{22} are positive in many oligopoly models, whereas $\pi_{12} = \pi_{21}$ tends to be negative. This introduces a possible counterveiling effect.

In this section, we first give conditions under which the turnover game will lead to an even distribution of educated workers; and in particular under which there will be no turnover in period 2 if both firms have chosen the same training levels in period 1.

Lemma 12 *Suppose that assumption 3 holds. Then there is an equilibrium of the poaching game with* $n^i = n^j = N$ *for arbitrary* g^i,g^j *such that* $g^i + g^j = 2N$. *In this equilibrium, each educated worker obtains wage offers* $w^*(N,N) = \widetilde{\pi}(N+1,2N) - \widetilde{\pi}(N,2N)$ *by both firms.*

Proof: We first show that, given the competitor's wage offers $w^*(N,N)$, lowering wages is not profitable. Suppose the firm reduces its wage offer to one worker. This deviation is not profitable if

$$\widetilde{\pi}(N,2N) - N \cdot w^*(N,N) \geq \widetilde{\pi}(N-1,2N) - (N-1) \cdot w^*(N,N).$$

Given equilibrium wages, this is equivalent to:

$$\widetilde{\pi}(N,2N) - \widetilde{\pi}(N-1,2N) \geq \widetilde{\pi}(N+1,2N) - \widetilde{\pi}(N,2N),$$

which follows from concavity. Similarly, concavity implies

$$\widetilde{\pi}(N-1,2N) - (N-1) \cdot w^*(N,N) \geq \widetilde{\pi}(N-2,2N) - (N-2) \cdot w^*(N,N).$$

By iteration, no downward deviation is favorable.

As to upward deviations, a higher wage offer for one worker would yield an increase in second period gross profits of $\widetilde{\pi}(N+1,2N) - \widetilde{\pi}(N,2N)$, which is exactly offset by the additional wage payment $w^*(N,N)$. By concavity, poaching any further worker would yield additional payoffs smaller than

$\widetilde{\pi}(N+1,2N)-\widetilde{\pi}(N,2N)$ and thus smaller than the additional wage payment. Hence, there are no profitable deviations.

Note, that the assumption of an even total number of educated workers can easily be dispensed with. In this case, there are two payoff-equivalent equilibria, in each of which one firm has one more worker than the other. We now use the lemma to provide a sufficient condition for an equilibrium with training.

Proposition 13 *Suppose assumption 3 holds. Suppose M is the maximum number of workers in each firm which can be trained. Further, suppose that among all $n \in \{1,...,M\}$*

$$\widetilde{\pi}\left(\frac{n+M}{2},n+M\right)- \frac{M+n}{2}\left[\widetilde{\pi}\left(\frac{n+M}{2},n+M\right)-\widetilde{\pi}\left(\frac{n+M}{2},n+M\right)\right]-n\cdot I$$

is maximal for $n=M$.
Then, there exists a subgame perfect equilibrium such that $g^i=g^j=M$, and there is no turnover in equilibrium.
Equilibrium wages are

$$w^*(M,M)=\widetilde{\pi}(M+1,2M)-\widetilde{\pi}(M,2M).$$

Proof: Total payoff in the proposed equilibrium is

$$\widetilde{\pi}(M,2M)-M\cdot[\widetilde{\pi}(M+1,2M)-\widetilde{\pi}(M,2M)]-M\cdot I.$$

As all workers are trained in the proposed equilibrium, it is sufficient to consider deviations to wage strategies leading to $n \leq M$. Assume for simplicity that $n+M$ is an even number.[18] By the lemma, the resulting

[18]The argument for the case when $n+M$ is not even requires some simple modification of the derivation since in equilibrium one firm has one more worker and their equilibrium wages are $\widetilde{\pi}\left(\frac{M+n+1}{2},n+M\right)-\widetilde{\pi}\left(\frac{M+n-1}{2},n+M\right)$.

subgame will yield payoffs

$$\widetilde{\pi}\left(\frac{n+M}{2}, n+M\right) - \frac{M+n}{2}\left[\widetilde{\pi}\left(\frac{n+M}{2}+1, n+M\right) - \widetilde{\pi}\left(\frac{n+M}{2}, n+M\right)\right] - n \cdot I.$$

Hence, downward deviations are not profitable.

Proposition 14 illustrates that the training equilibrium generalizes to arbitrary many workers as long as competition is sufficiently soft. If $\widetilde{\pi}(M+1, 2M) - \widetilde{\pi}(M, 2M)$ is concave in M which occurs if there are decreasing returns to human capital accumulation, wages for trained workers are decreasing in the number of trained workers. It remains open in which types of oligopoly models, the condition of proposition (14) is fulfilled.

6 Conclusions and Extensions

In this paper, we provided a theory of why firms invest in general training of employees. Unlike previous work, our explanation does not rely on asymmetric information on the labor market. Instead, we require imperfect product market competition to generate equilibria with general training in a world where turnover is endogenous.

We also identify further parameters that are likely to determine whether training arises as an equilibrium phenomenon. Particularly important is the extent to which the benefits of general training remain in the firm once a trained employee leaves. As polar cases, we distinguish between "worker" training where no improvements remain after the employee has left, and "manager" training where all the improvements remain even after the departure. In the worker case, we show that an equilibrium without training arises for arbitrary parameter constellations, but in many cases an equilibrium with training also exists, leading to a potential coordination role for the state. In the manager case, equilibria with training are more likely than in the worker case.

Another crucial parameter is the extent of complementarity between education of different workers. The training equilibrium in the worker case is shown to rely on the assumption that profits are a concave function of the number of trained workers in the firm, which essentially says that there are no complementarities in the education of different workers.

The arguments have been cast in a duopoly framework. They appear to hold more widely in an oligopolistic framework, but it remains to be seen how the number of firms in a market affects the likelihood of a training equilibrium. This will be the subject of future work.

APPENDIX

Proof. of Lemma 3: We start by proving (a). First note that the proposed wages are the only conceivable equilibrium strategies with mutual turnover. Higher wages are weakly dominated; lower wages would mean that the competitor would have an incentive to keep his employee. It remains to be shown that they constitute a Nash equilibrium. By lemma (2) and the symmetry of the equilibrium, it suffices to check three deviations for firm i.

(1) it is not profitable for firm i to set the wage for its own employee high enough to avoid turnover to the other firm, but at the same time leave the wage offer for the other firm's worker unchanged so that it obtains his human capital. This condition can be stated formally as:

$$\pi\left(y_m\left(1,1\right),y_m\left(1,1\right)\right)-w_{ij}\geq\pi\left(y_{in}\left(1,1\right),y_{out}\left(1,1\right)\right)-w_{ii}-w_{ij}.$$

Inserting the equilibrium wage, this becomes

$$\pi\left(y_m\left(1,1\right),y_m\left(1,1\right)\right)\geq\pi\left(y_m\left(1,1\right),y_m\left(1,1\right)\right).$$

(2) It is not profitable to reduce the wage offer for the other firm's worker without changing the offer for its own employee, and therefore forego the benefits from poaching, while letting the other firms reap the benefits of poaching. This condition requires:

$$\pi\left(y_m\left(1,1\right),y_m\left(1,1\right)\right)-w_{ii}\geq\pi\left(y_{out}\left(1,1\right),y_{in}\left(1,1\right)\right).$$

Inserting the value of w_{ii} gives

$$\pi\left(y_m\left(1,1\right),y_m\left(1,1\right)\right)-\pi\left(y_{in}\left(1,1\right),y_{out}\left(1,1\right)\right)+\pi\left(y_m\left(1,1\right),y_m\left(1,1\right)\right)\geq\pi\left(y_{out}\left(1,1\right),y_{in}\left(1,1\right)\right),$$

which holds by assumption 1.

(3) It is not profitable to reduce the wage offer for the other firm's worker and increase the wage offer for its own worker to $w_{ii}+\varepsilon$ so that there will be no turnover. This holds if

$$\pi\left(y_m\left(1,1\right), y_m\left(1,1\right)\right) - w_{ij} \geq \pi\left(y_n\left(1,1\right), y_n\left(1,1\right)\right) - \left(w_{ii}+\varepsilon\right),$$

which follows from assumption 2 and from $w_{ii} = w_{ij}$ in equilibrium. Therefore, there exists no profitable deviation for firm i and thus an equilibrium with mutual poaching exists.

We next prove (b).
In the proposed equilibrium one firm employs both workers. Suppose this is firm 1. Then firm 1's best response conditions (BRC) are as follows:

$$\text{(i) } \pi\left(y_{in}\left(1,1\right), y_{out}\left(1,1\right)\right) - w_{12} - w_{11} \geq \pi\left(y_{out}\left(1,1\right), y_{in}\left(1,1\right)\right)$$

$$\text{(ii) } \pi\left(y_{in}\left(1,1\right), y_{out}\left(1,1\right)\right) - w_{12} \geq \pi\left(y_n\left(1,1\right), y_n\left(1,1\right)\right)$$

$$\text{(iii) } \pi\left(y_{in}\left(1,1\right), y_{out}\left(1,1\right)\right) - w_{11} \geq \pi\left(y_m\left(1,1\right), y_m\left(1,1\right)\right)$$

For example, consider the first condition. This makes sure firm 1 does not deviate by reducing its wage offers to both workers, so that they both work for the competitor. Doing so would lead to wage savings of $w_{11}+w_{12}$. (i) makes sure these wage savings do not exceed the resulting drop in profits. The other conditions follow by similar considerations.

The BRC for firm 2 are

$$\text{(iv) } \pi\left(y_{out}\left(1,1\right),y_{in}\left(1,1\right)\right) \geq \pi\left(y_{in}\left(1,1\right),y_{out}\left(1,1\right)\right) - w_{12} - \left(w_{11}+\varepsilon\right)$$

$$\text{(v) } \pi\left(y_{out}\left(1,1\right),y_{in}\left(1,1\right)\right) \geq \pi\left(y_{n}\left(1,1\right),y_{n}\left(1,1\right)\right) - w_{12}$$

$$\text{(vi) } \pi\left(y_{out}\left(1,1\right),y_{in}\left(1,1\right)\right) \geq \pi\left(y_{m}\left(1,1\right),y_{m}\left(1,1\right)\right) - \left(w_{11}+\varepsilon\right)$$

For example, consider condition (iv). This makes sure firm 2 does not deviate by paying the minimum wages $w_{11}+\varepsilon$ necessary to obtain the services of the other firm's worker and keep its own worker by matching the competitor's offer w_{12}. (v) and (vi) have similar interpretations.
Conditions (i) to (vi) can be summarized as follows.
(i) and (iv) hold if and only if

$$\begin{aligned}\text{(vii) } &\pi\left(y_{in}\left(1,1\right),y_{out}\left(1,1\right)\right) - \pi\left(y_{out}\left(1,1\right),y_{in}\left(1,1\right)\right) \geq w_{12}+w_{11} \geq \\ &\qquad \pi\left(y_{in}\left(1,1\right),y_{out}\left(1,1\right)\right) - \pi\left(y_{out}\left(1,1\right),y_{in}\left(1,1\right)\right) - \varepsilon\end{aligned}$$

which implies $w_{12}+w_{11} = \pi\left(y_{in}\left(1,1\right),y_{out}\left(1,1\right)\right) - \pi\left(y_{out}\left(1,1\right),y_{in}\left(1,1\right)\right)$ up to ε.
To satisfy (iii)/(vi) and (ii)/(v) we need

$$\begin{aligned}\text{(viii) } &\pi\left(y_{in}\left(1,1\right),y_{out}\left(1,1\right)\right) - \pi\left(y_{m}\left(1,1\right),y_{m}\left(1,1\right)\right) \geq w_{11} \geq \\ &\qquad \pi\left(y_{m}\left(1,1\right),y_{m}\left(1,1\right)\right) - \pi\left(y_{out}\left(1,1\right),y_{in}\left(1,1\right)\right) - \varepsilon\end{aligned}$$

$$\begin{aligned}\text{(ix) } &\pi\left(y_{in}\left(1,1\right),y_{out}\left(1,1\right)\right) - \pi\left(y_{n}\left(1,1\right),y_{n}\left(1,1\right)\right) \geq w_{12} \geq \\ &\qquad \pi\left(y_{n}\left(1,1\right),y_{n}\left(1,1\right)\right) - \pi\left(y_{out}\left(1,1\right),y_{in}\left(1,1\right)\right)\end{aligned}$$

Condition (viii) and (ix) are conditions on wages and profits. The profit condition in (viii) is equivalent to $\pi\left(y_{in}\left(1,1\right),y_{out}\left(1,1\right)\right)+\pi\left(y_{out}\left(1,1\right),y_{in}\left(1,1\right)\right)\geq 2\pi\left(y_{m}\left(1,1\right),y_{m}\left(1,1\right)\right)-\varepsilon$ and thus to the condition in lemma 2. Similarly, the profit condition in (ix) requires that $\pi\left(y_{in}\left(1,1\right),y_{out}\left(1,1\right)\right)+\pi\left(y_{out}\left(1,1\right),y_{in}\left(1,1\right)\right)\geq 2\pi\left(y_{n}\left(1,1\right),y_{n}\left(1,1\right)\right)$ which is implied by (viii) because of assumption 2.

To sum up, in equilibrium $w_{12}+w_{11}$ must be equal to $\pi\left(y_{in}\left(1,1\right),y_{out}\left(1,1\right)\right)-\pi\left(y_{out}\left(1,1\right),y_{in}\left(1,1\right)\right)$. Individual wages are not determinate but wages $w_{11}=\pi\left(y_{M}\left(1,1\right),y_{M}\left(1,1\right)\right)-\pi\left(y_{out}\left(1,1\right),y_{in}\left(1,1\right)\right)$ and $w_{12}=\pi\left(y_{in}\left(1,1\right),y_{out}\left(1,1\right)\right)-\pi\left(y_{m}\left(1,1\right),y_{m}\left(1,1\right)\right)$ satisfy the equilibrium conditions (vii) to (ix). These choices of w_{11} and w_{12} are part of the equilibrium where $w_{22}=w_{12}-\varepsilon$; $w_{21}=w_{11}$. There are infinitely many other combinations satisfying (vii)-(ix), but they cannot be distinguished in terms of payoffs for firms since the sum of the wages paid remains the same.
If $\pi\left(y_{in}\left(1,1\right),y_{out}\left(1,1\right)\right)+\pi\left(y_{out}\left(1,1\right),y_{in}\left(1,1\right)\right)<2\pi\left(y_{m}\left(1,1\right),y_{m}\left(1,1\right)\right)-\varepsilon$ the equilibrium condition (viii) is violated, and thus no equilibrium with asymmetric turnover (poaching) occurs. If the condition in b) is not fulfilled, case a) occurs.

(c) Suppose without loss of generality that $w_{ii}\geq w_{jj}$. Then for w_{ii} to be a best response and generate no turnover, it is necessary that firm i does not prefer poaching the competitor's worker and letting his own worker go. Thus, we require $\pi\left(y_{n}\left(1,1\right),y_{n}\left(1,1\right)\right)-w_{ii}\geq\pi\left(y_{m}\left(1,1\right),y_{m}\left(1,1\right)\right)-w_{jj}$, and hence $\pi\left(y_{n}\left(1,1\right),y_{n}\left(1,1\right)\right)\geq\pi\left(y_{m}\left(1,1\right),y_{m}\left(1,1\right)\right)$.

By analogous reasoning, if $\pi\left(y_{n}\left(1,1\right),y_{n}\left(1,1\right)\right)=\pi\left(y_{m}\left(1,1\right),y_{m}\left(1,1\right)\right)$, all wages must be the same. The only conceivable symmetric equilibrium is $\pi\left(y_{in}\left(1,1\right),y_{out}\left(1,1\right)\right)-\pi\left(y_{n}\left(1,1\right),y_{n}\left(1,1\right)\right)$: higher wages are weakly dominated, for lower wages, the competitor would have an incentive to overbid. ∎

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