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ABSTRACT

Wage Competition with Heterogeneous Workers and Firms*

We study imperfect competition in the labour market when worker skills are continuously distributed within the population and a finite number of firms have different job requirements. The cost of training a worker depends on the difference between this worker's skill and the employer's needs. When firms cannot identify worker training costs in advance, firms pay workers equal wages, but workers absorb training costs. When firms can identify worker types before employment, firms can pay different net wages to workers with different training costs. Voters select the level of general education which is financed by a lump-sum tax. Workers are on average better off when firms can observe workers' skill for a given level of human capital, but the median voter prefers a higher level of general human capital when firms cannot observe worker types.

JEL Classification: J41, I22
Keywords: wage competition, job assignment, information structure, median voter

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NON-TECHNICAL SUMMARY

In this paper, workers are heterogeneous in the type of work they are best suited for, while firms are also heterogeneous in their job requirements. Specifically, the interaction between firms and workers is modeled here by means of a monopsonistic competitive market inspired by Salop (1979), in which the skill space substitutes for geographical space while training costs are the counterpart of transport costs. Such an analogy implies that the labour market is viewed as a setting in which firms use different technologies and compete to attract workers. Since workers and firms are both heterogeneous, this yields important insights about the roles of training and schooling. The strength of this approach is to show how individuals who vary in skills can adjust to any given configuration of technologies by acquiring the necessary training. By adding to this model a political economy dimension in which people choose the level of general education in anticipating its impact on the labour market, our model also allows us to study some meaningful facets of the interaction between schooling and training through the interplay between market behaviour and voting.

More precisely, once it is recognized that workers are heterogeneous, it should be clear that two (polar) cases may arise depending on the kind of job, the nature of the industry and the institutional context. In the first case, firms cannot observe the cost of training a worker but the worker knows this cost. In the second one, both the worker and the firm can observe the cost of training the worker prior to employment. Since the information structure is likely to vary with the specifics of the labour market, our framework thus shows that wage formation depends crucially on the industry as well as on the type of job. In particular, the difference in information structure allows us to determine how specific training costs are split between workers and firms.

The difference in the information structure turns out to have a dramatic impact on the workers' earnings since workers hired by a firm are not drawn randomly from the work force as a whole. In particular, we find that the effect of a decrease in the quality of the job match differs in the two information regimes. Under asymmetric information where the worker absorbs training costs, the worker is worse off with a poorer match. On the contrary, under full information, workers are better off with poorer matches because they have better matches in the alternative jobs. This may seem paradoxical but a moment's reflection shows that the more distant worker has more bargaining power because the distance to the second nearest firm is smaller, thus forcing this firm to make a higher wage offer. Another distinctive implication of the two information structures is the difference in the distribution of earnings. Under asymmetric information, the distribution of earnings mirrors the match

distribution. When there is full information, this relationship is reversed since the workers with a poor match appear to be those who have a high bargaining power due to the fact that they are close to the best outside option. Last, we show that for the same level of general human capital, wage dispersion is lower under asymmetric information.

Though there is no one-to-one correspondence, a fairly natural interpretation of the first setting seems to be that of a thick market in which many people apply for a few jobs, thus making it very difficult for firms to observe workers' abilities. This is typically what happens for low-skilled or blue-collar workers. In the second setting, the labour market would be thin in that there are only a few candidates for each job. Since it is relatively easy to identify workers when there are not many, it is reasonable to assume that workers' abilities are observable by firms. One may think of the market for managers or high-skilled workers where, after a while, everybody knows everybody else. The academic market is also a good example of such an informational structure.

We then study the choice of the level of general human capital - how much to invest in education. The level of general human capital is chosen at the political equilibrium whose outcome is given by the preferences of the median voter earning her long-run wage. The utility of a worker equals this wage since firms make zero profits in long-run equilibrium so that social welfare equals total income net of general training costs. The assumption of publicly financed general education reflects the fact that in OECD countries other than Japan and the US, general education is publicly provided, and, even in Japan and the US, public provision is important, especially below the university level. On average, public funding covers almost 90% of education costs in advanced industrialized countries, thus making this assumption reasonable. The government finances its provision through lump-sum taxes. We find that that the median voter's net wage under asymmetric information is lower than the one under full information for the same level of general human capital. However, under asymmetric information, the median voter chooses to invest more in general human capital. Consequently, it is ambiguous in which information structure the median voter is better off, depending on the curvature of the training cost function.

1 Introduction

A distinguishing feature of modern advanced economies is the importance of education and training as a source of productivity growth. Individuals obtain a variety of skills in formal schooling, but it has long been recognized that formal schooling is not the only important form of training of the labor force. Firms spend vast sums of money on training their labor forces to develop particular skills and to learn to work with new technologies, both in formal programs and in less formal on-the-job training. In addition, every individual has idiosyncratic characteristics that make her more suitable for some jobs than other people, regardless of the education received in schools.

Since the pioneering work of Becker (1964) and others on human capital, economists have modeled the demand for education using investment theory. A key question underlying this strand of research has been who pays for training of workers–employers or the workers themselves. Not surprisingly, the answer turns out to depend on the type of human capital. The conventional wisdom is that workers (or taxpayers …nancing education) pay for investment in general human capital, while …rms and workers share in the cost of investment in speci…c human capital (Hashimoto, 1981; Parsons, 1986). The …rst type of training creates abilities which have value to all …rms (or at least a large number of …rms) in the economy. The second type of training creates speci…c abilities which have value to only a single …rm. Since the …rm employing a worker has no market power with respect to the worker's general human capital, the worker can extract the entire return to it and, hence, must pay the full cost of investment. With speci…c human capital, the …rm has market power ex post, but the worker's potential mobility across …rms prevents the …rm from being willing to pay all of the investment cost. Indeed, potential mobility determines the distribution of the cost between the worker and the …rm in these models of shared costs and shared returns. The typical setting involves one …rm, one worker, and an exogenous outside job alternative.

In this paper, we follow a di¤erent path by assuming a population of workers who are heterogeneous in the type of work they are best suited for, while …rms are also heterogeneous in their job requirements. Our primary purpose is then to show how such heterogeneity in‡uences the distribution of output between workers and employers. Once it is recognized that the labor force is heterogeneous in the skill space, it should be clear that …rms have incentives to di¤erentiate their technologies. Indeed, as Stevens (1994) argues, …rms are then able to obtain market power in the labor market which allows them to set wages below the productivity of workers.[1]

Speci…cally, the interaction between …rms and workers is modeled here by means of a monopsonistic competitive market inspired by Salop (1979), in which the skill space substitutes for geographical space while training costs are the counterpart of transport costs. Such an analogy implies that the labor market is viewed as a setting in which …rms use di¤erent technologies and compete to attract workers. Since workers and …rms are both heterogeneous, this yields important insights about the roles of training and schooling. The strength of this approach is to show how individuals who vary in skills can adjust to any given con…guration of technologies by acquiring the necessary training. By adding to this model a political economy dimension in which people choose the level of general education in anticipating its impact on the labor market, our model also allows us to study some meaningful facets of the interaction between schooling and training through the interplay between market behavior and voting.

Unfortunately, the model assumes symmetry among …rms for tractability, thus precluding the possibility to discuss the particular attributes of technologies. Hence, we have little to say about the impact of skill biased technologies on wage formation. However, we believe that the principles and methods we develop could also be useful to revisit models dealing with vertical earning structures (as in hierarchical models of job assignment) once it is recognized that heterogeneity in skill levels (instead of skill types) is another source of heterogeneity that endows …rms with monopsony power on the labor market. If so, this would lead to a uni…ed framework permitting the analysis of di¤erent kinds of heterogeneities in the labor force as well as among …rms operating within the same industry.

When workers and …rms are heterogeneous, it is clear that the information available to …rms about workers matters in the process of wage formation. In the interaction between …rms and workers, (at least) two di¤erent information structures and, consequently, two di¤erent ways of sharing the costs and returns of training may arise. In the …rst one, …rms cannot observe the cost of training a worker but the worker knows this cost. In the second one, both the worker and the …rm can observe the cost of training the worker prior

[1] In the same spirit, Mills and Smith (1996) show that …rms have a strategic incentive to choose di¤erent technologies to get more monopoly power on the product market. Other reasons for heterogeneity in …rms' technologies are surveyed by Mills and Smith (1996).

to employment. Since the information structure is likely to vary with the speci…cs of the labor market, our framework thus shows that wage formation depends crucially on the industry as well as on the type of job. In particular, the di¤erence in information structure allows us to determine how speci…c training costs are split between workers and …rms.

Previewing our results, the di¤erence in the information structure turns out to have a dramatic impact on the workers' earnings since workers hired by a …rm are not drawn randomly from the work force as a whole. When a …rm does not observe training costs, it o¤ers the same wage to all potential employees but makes them bear the training costs. Workers then select a …rm which o¤ers them higher net earnings than other …rms. More precisely, workers whose skills are close to a …rm's job requirement will be hired by this …rm. As a consequence, self-selection leads to an endogeneous segmentation of the labor market. On the other hand, when both …rms and workers are able to observe the training cost prior to employment, each worker is engaged in a bargaining process with the nearest …rm, using the potential o¤er of the second nearest …rm as an alternative option.

As will be seen below, the corresponding distributions of earnings are very di¤erent in the two cases. In the former, the workers with the best match get the highest earnings. In the latter, workers with the highest bargaining power (who are the poorest matches vis-a-vis the …rm which employs them, but the best matches with an alternative …rm) earn the highest net wages. Though there is no one-to-one correspondence, a fairly natural interpretation of the …rst setting seems to be that of a thick market in which many people apply for a few jobs, thus making it very di¢ cult for …rms to observe workers' abilities. This is typically what happens for low-skilled or blue-collar workers. In the second setting, the labor market would be thin in that there are only a few candidates for each job. Since it is relatively easy to identify workers when there are not many, it is reasonable to assume that workers' abilities are observable by …rms. One may think of the market for managers or high-skilled workers where, after a while, everybody knows everybody else. The academic market is also a good example of such an informational structure, as suggested by the empirical …ndings of Ransom (1993) about the US academic market.[2]

Our model is related to several existing models of the labor market. For

[2] Speci…cally, Ransom looks at di¤erential mobility costs, but the issue is still observability by potential employers.

example, it may be viewed as an assignment model with a large number of workers and a small number of jobs (or firms) which is non-hierarchical since there is no ranking in any sense of the workers' types (Sattinger, 1993). In particular, our model bears some resemblance to Roy's (1951) in that workers choose among only a few jobs and only a subset of workers can be found in a given job (or firm). However, our model differs in two fundamental ways. First, while Roy considers a job as a (competitive) sector, we view jobs as a set of firms belonging to the same sector and behaving strategically. Second, we are interested in the way the output produced by a worker is shared between the worker and the employer when the labor market is imperfectly competitive, and not in the distribution of earnings per se.

Furthermore, Chang and Wang (1996) consider a setting in which a firm derives market power over its incumbent workers from the fact that rival firms do not know how much specific training these workers have acquired. By contrast, in our model, firms have market power because they are able to exploit the advantage of proximity in the skill space on those workers whose skills are close to their job requirement. However, it remains true that the information structure has a major impact on wage formation, although it is not the reason for firms' market power.

Our secondary purpose is to study voters' choice of taxes to fund investment in general human capital, conditional upon the wage-setting processes considered above. The assumption of publicly financed general education reflects the fact that in OECD countries other than Japan and the US, general education is publicly provided, and, even in Japan and the US, public provision is important, especially below the university level. On average, public funding covers almost 90% of education costs in advanced industrialized countries, thus making this assumption reasonable. The government finances its provision through lump-sum taxes. We find that workers choose to invest in more general human capital under asymmetric information.

The remainder of the paper is organized as follows. Section 2 describes the model and the two alternative information structures. In Section 3, we solve the asymmetric information model for a given level of general human capital. Section 4 analyzes the full information model. In Section 5, we compare outcomes in the two models whereas, in section 6, we analyze the level of investment in general human capital by means of a voting scheme. Section 7 contains our conclusions and discusses avenues for further research.

2 The model

Consider an industry with n …rms producing a homogeneous good sold on a competitive market (we take this good as the numéraire). For simplicity, a …rm is fully described by the type of worker it needs. This means that a job is a collection of tasks determined only by the technology used by the …rm (Lazear, 1995). Firm i's $(= 1; :::n)$ skill requirement is denoted by x_i. Labor is the only input and production involves constant returns to scale once some entry cost measured in terms of the numéraire is paid.

There is a continuum of workers with the same level of general human capital, but they have heterogeneous skills. Let g be the common level of general human capital. Workers are heterogeneous in the type of work they are best suited for, but there is no ranking in any sense of these types of work. Workers' skill types are denoted by x. The characteristics of a worker relevant to …rms are summarized by her skill. The government's education policy determines the common level of general human capital g for all workers. Finally, each worker supplies one unit of labor provided that her wage net of training costs paid by the worker (her earnings) is positive (without loss of generality, the reservation wage is normalized to zero).

Each …rm has a speci…c technology such that workers can produce output only when they perfectly match the …rm's skill needs. Since workers are heterogeneous, they have di¤erent matches with the …rm's job o¤er. Thus, if …rm i hires a worker whose skill di¤ers from x_i, the worker must get trained and her cost of training to meet the …rm's skill requirement is a function of the di¤erence between the worker's skill x and the skill requirements x_i.

In other words, we develop a non-hierarchical assignment model which can be viewed as complementary to hierarchical assignment models. Indeed, the assignment literature emphasizes ex ante di¤erences among workers and …rms whereas the job matching literature is primarily concerned with ex post di¤erences in the output obtained from worker-…rm combinations (Sattinger, 1993, p.835). However, unlike Sattinger who focuses on vertical structures, we consider a labor market in which workers and …rms are horizontally di¤erentiated. More precisely, Sattinger (1993) assumes that workers are heterogeneous with respect to g and homogeneous with respect to x. By contrast, we consider a model in which g is identical while x varies across workers. Such an approach allows us to account for some inherent and idiosyncratic characteristics of workers that make the population of equally educated individuals unequally suitable from the …rms' perspective.

Once it is recognized that workers are heterogeneous, it should be clear from our discussion in the introduction that two (polar) cases may arise depending on the kind of job, the nature of the industry and the institutional context. In the first case, firms cannot identify an individual's skill prior to employment, but know the statistical distribution of individual skills. In the second, firms have detailed information about each worker's characteristics.

For simplicity, the skill space is described by the circumference C of a circle which has length L. Individuals' skills are continuously and uniformly distributed along this circumference; the density is constant and denoted by ¢. The density ¢ expresses the size of a market. Hence, as discussed in the introduction, a thick market arises when ¢ is large whereas a thin market corresponds to a small value of ¢. The parameter L measures the degree of diversity in workers' skills. Whereas ¢ expresses the number of workers of each type, L is a measure of the heterogeneity of workers in the labor market. When the population of workers is heterogeneous, the extent of the labor market must be described by these two parameters. We will see that they play different roles in the market equilibrium. Firms' job requirements x_i are equally spaced along the circumference C so that L/n is the distance between two adjacent firms in the skill space.[3]

The training cost function is $s(g)\,|x - x_i|$, where $s(g)$ expresses the ability of a worker to learn how to adjust to a technology different from her skill. Workers with more general human capital learn at a lower cost so that $s(g)$ is decreasing in g. After training, all workers are identical from the firm's viewpoint since their ex post productivity is observable and equal to g by convention (thus, there is no moral hazard problem within firms). Everything else being equal, more investment in schooling (general human capital) leads to lower training cost (specific human capital), so they are substitutes in education. It is worth noting that here specific human capital is measured by $s(g)\,|x - x_i|$ which depends on both the firm (x_i) and the worker's skill (x).

Let us first consider the case where the firms do not observe the workers' types. However workers know their own types and observe the firms' skill needs. In order to induce the appropriate set of workers to take jobs with the most suitable firm, workers must pay at least some part of the cost of

[3] By analogy with what has been shown on a differentiated product market, the equidistant configuration of technologies is likely to be an equilibrium outcome of a game in which firms would choose their technologies prior to their wages (see, e.g., Economides (1989) and Kats (1995))

training. In addition, since the supply of a worker is inelastic, firms cannot offer a wage menu so that the worker must pay for all the costs of training which are not observable to the firm (hence resolving the adverse selection problem).

Consequently, each firm i offers a wage to all workers, conditional on the worker having been trained to the skill x_i. Since all workers who have received specific training are ex post identical in the eyes of the firm, it offers them only a single wage. Each worker then compares the wage offers of firms and the required training costs; she simply chooses to work for the firm offering the highest wage net of training costs. The training costs and the wages are in present value terms (we have collapsed the model to a single period for simplicity).[4]

In the second case, firms are able to identify workers' types before hiring and, therefore, how much it will cost to train each worker to their particular job requirement. In present value terms, workers care only about their net wages, and it does not matter which party formally pays the training costs. A firm can make different net wage offers to workers of different types because the workers have different job opportunities with rival firms.

In either context, the wage-setting game proceeds as follows. First, firms simultaneously choose their gross wage offers. Workers then observe all wage offers and choose to work for the firm that yields the highest net wage. Since each firm anticipates workers' choices, it is willing to hire all workers who prefer to work for it. In equilibrium, there are no quits or layoffs because both firms and workers have no incentive to deviate. The allocation of workers among firms is based entirely on individual competitive advantage. It should also be noted that, though some models of human capital suggest that only individual characteristics matter for earnings, while job characteristics are the major determinant of earnings in segmented labor market theories, both sets of variables turn out to be critical in our model. This feature is shared with the assignment models developed by Sattinger (1993). Throughout the paper, we assume that the level of general human capital (g) is the same

[4] Observe that our model differs from Gottfries and McCormick (1995) in which firms do not observe ex ante workers' productivity but training costs are fixed and independent of the initial skill of workers. Hence there is still heterogeneity ex post, so that the possibility of adverse selection arises in their model. The assumption of a fixed training cost seems peculiar and we find the assumption of worker-specific training costs more reasonable. Because workers are ex post identical in our model, the adverse selection problem disappears.

regardless of the industry and thus the job under consideration. This is because we want to contrast and compare the two polar cases described above.

3 Labor market equilibrium when workers' skills are not observable

In this section, we study the case when firms are not able to identify the skill type of any individual worker. Prior to hiring a worker, however, each firm knows the distribution of worker skills in the population. The wage determination game proceeds as follows.

Consider firm i. If the firms on either side of it offer wages w_{i-1} and w_{i+1}, respectively, then firm i's labor pool consists of two sub-segments whose outer boundaries are $\bar{x}$ and $\bar{y}$: The worker at $\bar{x}$ receives the same net wage from firm i and firm $i-1$, while the worker at $\bar{y}$ receives the same net wage from firm i and firm $i+1$. Since firm i knows the training cost function and all firms' job requirements, it can determine $\bar{x}$ and $\bar{y}$. Specifically, $\bar{x}$ is the solution to the equation: $w_i - s(g)(x_i - \bar{x}) = w_{i-1} - s(g)(\bar{x} - x_{i-1})$, so that

$$\bar{x} = \frac{w_{i-1} - w_i + s(g)(x_i + x_{i-1})}{2s(g)}. \tag{1}$$

Firm i attracts workers whose skill type lies in the interval $(\bar{x}; x_i]$ because they obtain a higher net wage from firm i than from firm $i-1$. Workers with skill types in $[x_{i-1}; \bar{x})$ prefer to work for firm $i-1$. Similarly, we can show that:

$$\bar{y} = \frac{w_i - w_{i+1} + s(g)(x_i + x_{i+1})}{2s(g)}. \tag{2}$$

Firm i's labor pool thus consists of all workers with skill types in the interval $[\bar{x}; \bar{y}]$. Its profits are given by:

$$\Pi_i = \int_{\bar{x}}^{\bar{y}} \cdot (g - w_i)dx = \cdot (g - w_i)(\bar{y} - \bar{x}). \tag{3}$$

For an exogenous number of firms, wages and profits at the Nash equilibrium can be determined as follows.

Proposition 1 *If firms do not observe workers' skills, then in an equilibrium in which all workers are employed, the wage is $w^*(n) = g - s(g)L/n$ and profits per firm are $\Pi^* = s(g)L^2/n^2$. Such an equilibrium exists when $g > 3s(g)L/2n$ holds.*

Proof. The profit function is continuous in (w_{i-1}, w_i, w_{i+1}) and concave in w_i. We can therefore guarantee that there exists a Nash equilibrium in wages. With firms located symmetrically, we find the Nash equilibrium wages by taking the first-order condition for Π_i with respect to w_i:

$$\frac{\partial \Pi_i}{\partial w_i} = -(\bar{y} - \bar{x}) + (g - w_i)\left(\frac{\partial \bar{y}}{\partial w_i} - \frac{\partial \bar{x}}{\partial w_i}\right) = 0. \tag{4}$$

From (1), (2) and (4), and setting equilibrium wages equal to each other, we obtain our formula. This solution is unique, since the first-order conditions are a system of linear equations in the wage of each firm. When $g > 3s(g)L/2n$ the worker with the worst match whose training cost is $s(g)L/2n$ will choose to work so that all workers are employed. ■

Before discussing this equilibrium, let us briefly describe what happens when the condition $g > 3s(g)L/2n$ does not hold. When $g < s(g)L/n$, then workers with a bad match withdraw from the market and each firm acts as a monopsonist and sets a wage equal to $g/2$. When $s(g)L/n \leq g \leq 3s(g)L/2n$, the labor pools just touch and all workers are hired at a wage $s(g)L/2n$.[5]

When skills are not observable, workers who receive less training also receive higher net wages. Though workers have the same level of general human capital and the same ex post productivity, they incur different training costs because of different matches. In addition, since firms do not discriminate between workers on the basis of their type, those with a better match end up with a higher net wage. This is easy to understand when it is recognized that both firms and workers are ex ante heterogeneous and that firms cannot discriminate in wages between workers of different skill types.

Furthermore, as the number of firms increases, equilibrium wages rise because adjacent firms compete for workers who are better matches. When the number of firms becomes arbitrarily large, the wage tends to the competitive

[5] See Jellal, Thisse and Zenou (1999) for a detailed analysis of the unemployment situation in a different but related framework.

level g, while profits tend to zero. The competitive model of the labor market is thus the limit of the spatial model of job assignment.

Finally, when g increases, gross productivity rises while the training cost of each worker decreases. As a result, the net wage increases with the level of general human capital, as supported by many empirical studies, while profits decrease because firms lose some of their monopsony power, an effect that overcomes the gain in productivity. When the number of firms is fixed, the equilibrium net wage dispersion, defined by the difference between the highest and lowest earnings and equal here to $s(g)L/2n$, decreases with the number of firms and with the general human capital level. Hence, the distribution of net earnings is less unequal when workers are more educated.

Each firm that enters the market must pay a positive fixed cost F. In the long-run free entry equilibrium, profits equal zero.[6]

Proposition 2 Assume that firms do not observe workers' skills. When all workers take a job, the equilibrium number of firms is $n^a = L\sqrt{s(g)\Delta/F}$, which increases with the size of the market and decreases with the level of fixed costs.[7]

Proof. From $\Pi^*(n^a) - F = 0$, using $w^*(n^a)$. ■

In other words, the long run number of firms rises with both the thickness (Δ) and the diversity of the labor market (L) but not at the same speed. Since a rise in general human capital reduces the firms' monopsony power, fewer firms will enter when g increases. It is readily verified that the long run equilibrium wage is:

$$w^a = g - \sqrt{\frac{s(g)F}{\Delta}}.$$

As expected, the long run equilibrium wage rises with g and with Δ. In words, this means that dense markets of educated workers, such as urban

[6] We use the superscript 'a' to denote equilibrium values in the asymmetric information model. Below the superscript 'f' will denote equilibrium values in the full information model.

[7] All workers take a job if the inequality of Proposition 1 ($g > 3s(g)L/2n$) is satisfied when n is replaced by n^a.

labor markets (Rauch, 1993), are associated with high wages. Finally, the equilibrium wage dispersion (the difference between the highest and lowest net wages) is now $(1/2)\sqrt{s(g)F/\phi}$, which decreases with the general human capital level but also with the market thickness.

We can now compare the equilibrium number of firms and the socially optimal number of firms, that is, the one which minimizes the sum of fixed costs and specific training costs.

Proposition 3 Assume that firms do not observe workers' skills. When all workers take a job, the socially optimal number of firms is $n^* = (L/2)\sqrt{s(g)\phi/F}$, which is one-half of the equilibrium number of firms.

Proof. Since all workers are hired, the socially optimal number of firms n minimizes:

$$SC(n) = nF + 2n\int_0^{L/2n} \phi s(g)x\,dx = nF + \frac{\phi s(g)L^2}{4n}.$$

This is convex in n, so we find the optimal value by differentiating with respect to n. ■

When workers' skills are not observable, strategic interactions on the labor market drive firms to excess entry and, therefore, insufficient training. Among other things, this implies that there is less than the socially efficient degree of wage dispersion.

4 Labor market equilibrium when workers' skills are observable

We now move to the model when firms are fully informed about the quality of individual job matches before hiring. Since each firm knows the skill type of each worker, firms can make different offers to workers of different skill types. The employer only cares about the sum of wage costs and its share of training costs, while the employee only cares about the wage net of any training costs she must bear. Thus, it is inessential who pays the training costs in that it is implicitly determined as part of the bargaining process.

Furthermore, we will see that, in this process, each worker plays the second nearest firm against the nearest one in order to secure the highest offer.

Let $l_i(x)$ denote the sum of training costs and the net wage received by an employee of skill type x who works for firm i. We can write profits for firm i as:

$$\pi_i = \int_{\underline{x}}^{\overline{x}} \cdot [g - l_i(x)]\, dx$$

where $\underline{x}$ and $\overline{x}$ are the outside boundaries of firm i's subsegments of the labor market. For workers with skill types in $[\underline{x}; x_i)$, firm $i-1$ can make the best alternative offer, while for workers with skill types in $(x_i; \overline{x}]$, firm $i+1$ can make the best alternative offer. Since the competition for a worker type is independent of the competition for any other worker type, the equilibrium net wages are easy to derive. Furthermore, in the case of a wage tie, we assume that workers choose the nearest firm because this one retains some leeway to raise its offer. In other words, one can view this as an ε-equilibrium in that the nearest firm can break the tie in wage offers by offering ε more than the competing rival.

Proposition 4 *If firms observe workers' skills, then in an equilibrium in which all workers are employed, workers with skill types in $[\underline{x}; x_i)$ receive net wages $w^f(x) = g - s(g)(x - x_{i-1})$, and workers with skill types in $[x_i; \overline{x}]$ receive net wages $w^f(x) = g - s(g)(x_{i+1} - x)$. Such an equilibrium exists when $g > s(g)L/n$ holds.*

Proof. Consider a worker in $[\underline{x}; x_i)$. Firm $i-1$ can offer no more than $g - s(g)(x - x_{i-1})$ and earn nonnegative profit from that worker's output. If firm i makes a lower wage offer firm $i-1$ will bid the worker away. Thus, $g - s(g)(x - x_{i-1})$ is the equilibrium wage offer to this type. The condition $g > s(g)L/n$ guarantees that all workers will be hired by the neighboring firms. ■

As with Proposition 1, we first briefly describe what the market outcome becomes when the condition $g > s(g)L/n$ does not hold. If $g < s(g)L/2n$, the workers with the worst matches cannot be employed since their training cost is higher than their ex post productivity; those who have a job are paid (net of training cost) their reservation wage because they cannot use the offer from the second nearest firm. When $s(g)L/2n \leq g \leq s(g)L/n$, all workers get a job. However, the workers with the best matches receive their reservation wage; the others are paid according to the schedule described in Proposition 4.

When firms can make personalized offers based on skill types, workers who receive more training now receive higher net wages. However, this is not because they are more productive than others, as in standard human capital models, but because their training costs at alternative firms are lower than others. Here workers who are poorly matched with a firm have a better outside alternative than others who are well matched with the same firm, thus increasing these workers' bargaining power. In particular, the worker with the worst match, that is, the worker in the middle of two firms, succeeds in capturing her ex post marginal productivity g net of her training costs $s(g)L/2n$. At the other extreme, the worker with the best match, that is, the worker at x_i, has the lowest pay equal to $g - s(g)L/n$. Consequently, wage dispersion is given by $s(g)L/2n$. For all these results to hold, it should be clear that firms and workers must be heterogeneous and that firms are able to discriminate in wages among workers of different skill types.

As in the section above, an increase in g leads to a rise in gross productivity and to a fall in training costs. Since, in equilibrium, the marginal worker $\hat{x}$ is at the middle of the segment joining firms $i - 1$ and i, all workers in $[\hat{x}, x_i)$ are hired by firm i so that the impact of g on the net wage is strictly positive. However, the workers who benefit more from this salary increase are those with a better match.

One should also note that our solution differs from that of Kim (1989) who uses a bargaining model of wage formation where the outside option (the wage offered in another industry) represents the threat point. The firm and the worker then split the surplus. This solution is not plausible because the threat point considered by Kim does not depend on the competitive environment which ensures the worker a better alternative than the outside option. More precisely, the competitive forces come from the adjacent firms since they give the worker higher wages than other competitors. Our solution corresponds to Bertrand competition in wages: the employer offers just enough to bid the worker away from the rival firm. Osborne and Rubinstein (1990, Section 9.2.2) show that this solution is an equilibrium of a game in which the buyers (here the firms) have different reservation values, that is, productivity net of training costs.

When all workers are hired, total training and wage costs for a worker with skill type x at firm i are:

$$l_i(x) = g - s(g)(x - x_{i-1}) + s(g)(x_i - x) \qquad \text{for} \qquad [\underline{x}; x_i); \qquad (5)$$

$$l_i(x) = g - s(g)(x_{i+1} - x) + s(g)(x - x_i) \qquad \text{for} \qquad [x_i; \bar{x}]: \qquad (6)$$

We are now able to obtain firms' equilibrium profits.

Proposition 5 Assume that firms observe workers' skills. When all workers take a job, equilibrium profits per firm before fixed costs are $\Pi^f = s(g)\Delta L^2/(2n^2)$ and the equilibrium number of firms with free entry is $n^f = L\sqrt{s(g)\Delta/2F}$, which exceeds the socially optimal number of firms.[8]

Proof. Substituting (5) and (6) into the profit function, we obtain:

$$\begin{aligned}
\Pi_i &= \int_{\underline{x}}^{x_i} \Delta\,[g - (g - s(g)(x - x_{i-1})) - s(g)(x_i - x)]\,dx \\
&\quad + \int_{x_i}^{\bar{x}} \Delta\,[g - (g - s(g)(x_{i-1} - x)) - s(g)(x - x_i)]\,dx \\
&= s(g)\Delta \left[\left(x_i^2 - \underline{x}^2\right) - (x_{i-1} - x_i)(x_i - \underline{x}) + (x_{i+1} + x_i)(\bar{x} - x_i) - \left(\bar{x}^2 - x_i^2\right)\right] \\
&= \frac{s(g)\Delta L^2}{2n^2}:
\end{aligned}$$

Setting Π_i equal to the fixed cost F, we obtain the equilibrium number of firms. ■

5 Comparisons between the two wage determination structures

Despite the fact that the two different wage and training cost structures arise from differences in information which are likely to be associated with differences in the labor market, it is instructive to compare the equilibrium outcomes controlling for Δ and for g.

Let $d \equiv |x - x_i|$ be the distance between a worker's skill type and that of her employer when the number of firms is n. Since workers are differentiated

[8] Again, all workers take a job if the condition of Proposition 4 ($g > s(g)L/n$) holds when n is replaced by n^f.

along a single characteristic, the value of d is sufficient to describe a worker completely. Let $c^a(d;n)$ and $c^f(d;n)$ denote her equilibrium (net) wage as a function of d. We know from Propositions 1 and 4 that

$$c^a(d;n) = g - s(g)\left(\frac{L}{n} + d\right) < g - s(g)\left(\frac{L}{n} - d\right) = c^f(d;n). \qquad (7)$$

Thus, when the number of firms is the same, workers' incomes under full information are always higher than the net wage under asymmetric information. This is because full-information wages are closer to marginal productivity. Despite the ability of each firm to exploit its information about a worker's skill type, the competitive forces drive firms to offer workers more with complete information. In contrast, with asymmetric information, each firm commits to a single wage, hence making the wage offer process less competitive than when firms compete for each and every worker separately. In other words, firms do not benefit from the gain in information about workers because competition on the labor market is fiercer under full information. Hence workers would be better off if they could reveal their types. However, each worker has an incentive to misreport her type since she would obtain a higher income by reporting a type more remote from the firm's skill needs than her actual type. Firms are aware of that and this makes it difficult for workers to reveal their type in a credible way.

Let $c^a(d)$ and $c^f(d)$ be the corresponding net wages at the free entry equilibrium. Using Propositions 2 and 5 and substituting in the equilibrium numbers of firms, we obtain:

$$c^a(d) = g - \sqrt{s(g)F/\Delta} - s(g)d \quad \text{and} \quad c^f(d) = g - \sqrt{2s(g)F/\Delta} + s(g)d. \quad (8)$$

When there is free entry the comparison between the long run net wages $c^a(d)$ and $c^f(d)$ becomes ambiguous and depends on the worker's type (d). This is so because competition on the labor market is fiercer for the incumbents under full information than under asymmetric information, thus inviting less entry so that some workers may be worse off in the full information case.

Furthermore, we find that the effect of a decrease in the quality of the job match differs in the two information regimes. Under asymmetric information where the worker absorbs training costs, the worker is worse off with a poorer match. On the contrary, under full information, workers are better off with poorer matches because they have better matches in the alternative jobs.

This may seem paradoxical but a moment's reflection shows that the more distant worker has more bargaining power because the distance to the second nearest firm is smaller, thus forcing this firm to make a higher wage offer.

Another distinctive implication of the two information structures is the difference in the distribution of earnings. Under asymmetric information, the distribution of earnings mirrors the match distribution. When there is full information, this relationship is reversed since the workers with a poor match appear to be those who have a high bargaining power due to the fact that they are close to the best outside option.

Turning to wage dispersion, in the asymmetric information case, we know that

$$c^a(0) - c^a\left(\frac{L}{2n^a}\right) = \frac{s(g)L}{2n^a} = \sqrt{\frac{s(g)F}{4\Delta}} \tag{9}$$

while in the full information case, the wage dispersion is equal to:

$$c^f\left(\frac{L}{2n^f}\right) - c^f(0) = \frac{s(g)L}{2n^f} = \sqrt{\frac{s(g)F}{2\Delta}}. \tag{10}$$

Hence, the net wages are not only higher under full information than under asymmetric information, but they are also more dispersed. On the other hand, all relevant parameters have the same impact (up to a factor of $1/\sqrt{2}$) on the wage dispersion in the two information structures. In particular, an increase in g or in Δ leads to a narrowing in wage dispersion which is stronger in the asymmetric information case.

As a final remark, we would like to stress the impact of a technological innovation on wage dispersion and aggregate training. For example, product innovation may require new and more sophisticated equipment, thus leading to an increase in the entry cost F, whereas cost innovation would typically allow firms to produce at lower costs, thus reducing F. Hence, depending upon the type of innovation, F may rise or fall with the adoption of an innovation. In the case where F increases (decreases), in both information settings, we see from (9) and (10) that wage dispersion becomes higher (smaller) although it increases (decreases) faster in the full information case than in the other. Since the total number of active firms is lower (higher) in the long run equilibrium, a rise (fall) in F leads to a worse (better) average match and thus to a rise (fall) in aggregate training.

A technological innovation may also require larger training costs $\bar{s}(g) > s(g)$ since workers must bear additional training costs to adjust to the new technology. As in the case of a rise in F, average training costs rise and wage dispersion increases in both settings. Clearly, when g is higher, the increase in aggregate training is smaller because the decrease in the number of active firms is less severe.

6 Choosing general human capital: a median voter approach

We now turn to the choice of the level of general human capital–how much to invest in education. The level of general human capital is chosen at the political equilibrium whose outcome is given by the preferences of the median voter earning her long-run wage. The utility of a worker equals this wage since firms make zero profits in long-run equilibrium so that social welfare equals total income net of general training costs (recall that the impact of fixed production costs and specific training costs is already accounted for in equilibrium wages). Since all workers have a job and the wage distribution is symmetric, maximizing median net wages is also equivalent to maximizing the net wage bill. Hence there is no conflict in this setting between the median voter's preferences and social welfare in the long-run free-entry equilibrium.

With the uniform distribution of skill types on the circle, the median and mean differences in net wage will be the same. Substituting in the equilibrium values for the median differences in skill requirements gives the median net wage that will be useful below. Under asymmetric information, we have:

$$\begin{aligned} c^a_{med} &= g^a - \sqrt{s(g^a)F/\phi} - \frac{s(g^a)L}{4L\sqrt{s(g^a)/F\,\phi}} \\ &= g^a - \frac{5}{4}\sqrt{s(g^a)F/\phi} \end{aligned} \tag{11}$$

while under full information, we get:

$$\begin{aligned} c^f_{med} &= g^f - \sqrt{2s(g^f)F/\phi} - \frac{s(g^f)L}{4L\sqrt{s(g^f)/2F/\phi}} \\ &= g^f - \frac{3}{2\sqrt{2}}\sqrt{s(g^f)F/\phi}. \end{aligned} \tag{12}$$

Let $v(g)$ be the per capita cost of producing g units of general human capital; we assume that v is increasing and convex in g. If general human capital can be financed with lump-sum taxes on workers, the median voter's problem is:

$$\max_{g} \left[c^{j}_{med} - v(g) \right] \qquad j = a; f: \tag{13}$$

Proposition 6 Assume that schooling and training are substitutes ($s'(g) < 0$) and that all workers take a job. Then, in the voting equilibrium, $g^a > g^f$ when general human capital investment is financed with a lump-sum tax.

Proof. Using (11), the first-order condition for the median voter's choice of g under asymmetric information is as follows:

$$1 - \frac{5}{8} \frac{s'(g)}{\sqrt{s(g)}} \sqrt{\frac{F}{\Delta}} - v'(g) = 0 \tag{14}$$

while, using (12), this condition under full information is given by:

$$1 - \frac{3}{4\sqrt{2}} \frac{s'(g)}{\sqrt{s(g)}} \sqrt{\frac{F}{\Delta}} - v'(g) = 0: \tag{15}$$

Define $k^a = 5/8$ and $k^f = 3/4\sqrt{2}$. Thus, both (14) and (15) can be rewritten in the following general way:

$$1 - k \frac{s'(g)}{\sqrt{s(g)}} \sqrt{\frac{F}{\Delta}} - v'(g) = 0 \tag{16}$$

where k equals k^a or k^f. By totally differentiating (16), we easily obtain:

$$\frac{dg}{dk} = \frac{\frac{s'(g)}{\sqrt{s(g)}} \sqrt{\frac{F}{\Delta}}}{-v''(g) - k \sqrt{\frac{F}{\Delta}} \left[\frac{s''(g)}{\sqrt{s(g)}} + \frac{1}{2}[s'(g)]^2 [s(g)]^{-\frac{3}{2}} \right]}: \tag{17}$$

From the second order condition, the denominator of (17) is negative. Accordingly, $dg/dk > 0$ since $s'(g) < 0$. The result then follows from the inequality $k^a = 5/8 > k^f = 3/4\sqrt{2}$. ■

The following comments are in order. First, inspection of (11) and (12) shows that the median voter's net wage under asymmetric information is lower than the one under full information for the same level of general human capital. However, under asymmetric information, the median voter chooses to invest more in general human capital. Consequently, it is ambiguous in which information structure the median voter is better off, depending on the curvature of the $s(g)$ function. In addition, the net wage gradient differ between the two solutions. Second, we know from (9) and (10) that wage dispersion is lower under asymmetric information for the same level of g. Proposition 6 strengthens this result since a higher g leads to a lower s. As a result, a labor market characterized by asymmetric information yields less wage dispersion. Lastly, the discussion above shows that the trade-off between general education and specific training is not the same in the two information regimes. This is because s depends on g. When it does not ($s'(g) = 0$), both levels of general human capital are the same since (14) and (15) are now identical and the solution depends only upon the relative numbers of firms in the long run.

In view of our discussion in Section 5 of the role of a technological innovation, we study the impact of a change in the entry cost F on the choice of education. Given (16), it is straightforward to see that an increase in F has the same positive impact on g as k. Hence, a product innovation requiring new and more sophisticated equipments leads to higher level of education in both information structures, whereas a cost innovation reducing F will be accompanied by a decrease in general human capital. Stated differently, depending upon the type of innovation, the level of education may rise or fall.

7 Conclusions

Though the model used in this paper may seem quite stylized, we believe that it captures some basic features of the interaction between a population of heterogeneous workers and a set of firms differing in their skill needs which have not been analyzed previously. In such a context, the structure of information is critical for the process of wage formation. On the one hand, when firms can observe the workers' skills, wages result from a bargaining process based on the alternative jobs a worker can take within the industry under consideration. On the other hand, under asymmetric information, all workers within the same labor pool are given the same gross wage set non-cooperatively by oligopsonistic firms. Consequently, in the latter, workers earn higher net wages as the job matching improves, whereas, in the former, net wages increase with the degree of job mismatch. Furthermore, we have seen that workers are on average better o¤ both in terms of net wages and education level when asymmetric information prevails.

We have considered two polar cases in which …rms cannot observe or can perfectly observe workers' skill. It would be interesting to investigate the intermediate cases where …rms have a priori some information about workers. This could be done by using a multiperiod model in which both …rms and workers learn about the quality of the job matching over time so that one could account for quits and layo¤s. Another possible extension would be to assume that workers remain heterogeneous after training as in Gottfries and McCormick (1995), thus opening the door to adverse selection problems. Except for imperfect competition (…nite number of …rms) and information asymmetries, our markets are frictionless–no queueing, unemployment, search costs–and more work is called for here to extend our framework.

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