12 How the adoption of a new technology is affected by the interaction between labour and product markets

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1 Introduction

It is commonly observed that firms in a given industry often use different technologies. Many explanations can be given such as the history of each firm, the existence of patents and licences or differences in skilled labour availability. These differences are often considered as exogenous in the industrial organisation literature although, at some point, they must result from firms' decisions. What should be clear, however, is that the use of different technologies directly affects the degree of competition in a given industry. In particular, equilibrium concentration is likely to reflect technological asymmetries so that the fact that some firms persist in using less efficient technologies could be viewed as a way to alleviate competition.

It has been argued that the adoption of different technologies may reflect strategic considerations. For example, in a completely symmetric environment, Mills and Smith (1996) show that the implications of technological choices at the product-competition stage may induce firms to choose different technologies. They consider a two-stage game in which firms pre-commit to technological choices in the first stage and compete in quantities in the second. They define particular technologies as specific combinations of fixed costs and constant marginal costs, a low marginal cost being associated with a larger fixed cost. In this context, once a firm has chosen the low-marginal-cost technology, the other firm may be better off choosing the high-marginal-cost technology and save on fixed costs. This leads to heterogeneous technological choices, and thus to a higher industry concentration in equilibrium. As argued by these authors, anti-trust policy tends to view conducts that increase industry concentration with suspicion but it turns out that in their model this conduct is precisely the one which induces the larger welfare.

In the present chapter, we also consider *a duopoly set-up in which technologies choices are made in a strategic context.* Firms are homogeneous *ex ante* and face the same opportunities in the adoption of a new technology. More precisely, we assume that an innovation process has been perfected and is freely available to all firms. In this context, firms must choose whether or not they adopt this new technology. However, we introduce labour market elements as a major determinant of technological choices.

To be more specific, we show that when firms take into account the effect of technological choices on labour market equilibrium, they can be led to make different choices, even though they face a completely symmetric opportunity set. Thus, we underline *the role of labour markets as a (possibly) major determinant of firms' strategical technological choices.* At a broader level, it can also be viewed as an attempt to model the interaction between product and labour markets in oligopolistic industries. This consideration has been widely neglected in the literature (with some important exceptions, such as Horn and Wolinsky, 1988; Ulph and Ulph, 1994; Gabszewicz and Turrini, 2000). This is somewhat paradoxical in view of the huge literature emphasising various forms of pre-commitments (in terms of products' characteristics, capacity levels, ...) as major strategic weapons aimed at relaxing product market competition. In this respect, labour is just one of these inputs over which pre-commitment is possible, if not natural. Typically, as soon as the functioning of labour markets entails some form of rigidity, there is room for some strategic behaviour aimed at relaxing competition in the product market. Taking explicit account of the strategic implications of labour market structures may well be part of the way towards this 'better understanding of how collusion works and what antitrust authorities should do – and can do – about it' advocated by Louis Phlips.[1]

The main intuition that underlies our chapter can be summarised as follows. An innovation process is often viewed as a cost-reducing innovation. The importance of the innovation is thus summarised by the *exogenous* marginal cost differential it leads to. Here, we adopt a slightly different view by stipulating that a process innovation consists in a more efficient technology in the sense that it increases the marginal productivity of labour. Note, then, that a higher marginal productivity of labour does not imply a lower marginal cost of production since labour market conditions may change owing to technological change. This is especially likely to happen since the adoption of a new technology may involve an adjustment of workers' skills. Reflecting this argument, we assume that workers must acquire a specific training when they work in the innovative

[1] Phlips (1995, p. 1).

firm. In other words, the adoption of the process innovation involves a specific training cost. This training cost will in turn lead to the emergence of a dual labour market structure in which the primary sector consists of innovative firms demanding high-skilled workers and the secondary one of standard firms with low-skilled workers. The adoption of the new technology by one firm at least thus affects the structure of the labour market. In order to model workers' behaviour in this context, we assume that the workforce is heterogeneous in its ability to acquire the specific training required in the primary sector. Workers' heterogeneity is central for the analysis to follow. Within this framework, the firm's problem is summarised as follows: in order to take advantage of the new technology, the firm must attract workers in the primary sector – i.e. induce some workers to bear (part of) the training cost; this is obviously achieved through higher wages. The labour market thus generates a negative externality that influences the choice of adopting the new technology. In a very simple framework of Cournot competition, we show that an innovation process which increases labour productivity may yield the three following potential subgame perfect equilibria (hereafter, SPEs) outcomes: no firm adopts the new technology; only one firm does it; both of them adopt it. In other words, the conditions prevailing in the labour market may affect the adoption of a new technology in an industry and generate heterogeneous technological choices.

The chapter is organised as follows. In section 2, we present the model. The Cournot subgames are discussed in section 3 and SPEs are characterised in section 4. In section 5, we discuss our results and section 6 draws some final conclusions.

2 The model

The firm

We consider the market for an *homogeneous product* whose inverse demand is given by $p = 1 - q$. Two firms are competing imperfectly in the product market. They choose quantities in order to maximise their profits in a non-cooperative way. Two technologies are available: the standard one, labelled S and the new one, labelled N. We assume that once technologies are adopted by firms, they use labour as their sole variable input.

Technology S yields a constant marginal productivity of labour which is normalised to 1 for simplicity. It does not require any training period to work in the firm that adopts S.[2] The new technology N is more efficient and

[2] Indeed, 'adopting' S basically amounts to sticking to the old technology for which workers are already adequately trained.

therefore exhibits a constant marginal productivity of labour equal to $a > 1$. However, it requires training costs that are exogenously shared between workers and firms (g is the fraction borne by workers).

In this context, we consider a *two-stage game* in which firms precommit to technological choices in the first stage and compete '*à la* Cournot' in the second stage.

The workforce

In order to model workers' behaviour, we adopt a framework inspired by the address models developed in product differentiation theories. Workers are endowed with one indivisible unit of labour and are all *heterogeneous*. Indeed, they all differ in their ability of acquiring skills and are uniformly distributed in a (compact) interval $[0, L]$ where L is arbitrarily large; $x \in [0, L]$ denotes the type of worker by measuring his unit training cost. The density in the interval $[0, L]$ is 1. Workers decide to work in the firm that offers the highest *net* wage.

The labour market

As stated in the introduction, there is a *dual labour market structure with heterogeneous workers*. The *secondary sector* is defined by firms that adopt the standard technology S which does not require training costs. We assume that in this sector the labour market is competitive and we denote by v the market-clearing wage. At this wage, a worker is indifferent between working in the secondary sector and being unemployed. In the context of an homogeneous workforce, this sector is typically viewed as a waiting sector since workers are always better off in the primary one (Burda, 1988; Saint-Paul, 1996). When the labour force is heterogeneous, this is not always true because of the training costs required in the primary sector (Wauthy and Zenou, 1997). The *primary sector* is composed of firms that adopt the new technology which entails a specific training cost. Without loss of generality we normalise it to a units. As stated above, we assume that the training cost is exogenously shared between firms and workers (g being the fraction borne by workers). When a firm adopts the new technology N there is a new labour market for specific skills since primary firms must set a wage above v to induce individuals to work there. We assume that the net wage associated with a skill acquisition of a units is defined by $w - gxa$ for a worker of type x. The reservation wage of a worker of type x for such a job is therefore equal to $v + gax$.

It should be clear by now that our view of the labour market is inspired by address models of vertical differentiation. The primary and secondary jobs are vertically differentiated in the sense that at equal wages, all workers would prefer to allocate their labour unit in the secondary sector in order to save on training costs. Moreover, workers differ in their willingness to work in the primary sector, depending on their defining attribute, as reflected in the distribution of reservation wages.

In both markets the wage is set non-strategically so as to clear the market.[3] In the primary sector, labour supply for a wage level w is given by the set of workers of types x for which $w - gxa \geq v$. We may thus express the labour supply in the primary market as follows:

$$L^S = \frac{w - v}{g \cdot a} \tag{12.1}$$

The labour demand in the same market is given by the aggregate demand of firms which depends on production decisions. By denoting the (aggregate) labour demand by L^D, the equilibrium wage in the primary sector is given by:

$$w = v + g \cdot a \cdot L^D \tag{12.2}$$

We are now able to characterise the firm's training cost under technology N. Consider first the case when only one firm is active in the primary sector and demands L^D workers. Given that the wage is chosen so as to equate supply and demand, the set of workers who supply their labour unit consists of workers of types $x \in [0, L^D]$. The total training cost borne by the firm is equal to:

$$TC^{NS} = \int_0^{L^D} a(1-g)x\,dx = \frac{a(1-g)}{2}(L^D)^2 \tag{12.3a}$$

Consider now the case when both firms adopt the new technology. We assume that workers are allocated randomly to jobs. In this case, the training cost is:

$$TC^{NN} = \frac{a(1-g)}{2}(L_1^D + L_2^D)L_1^D \tag{12.3b}$$

Observe that when firms bear all the training cost – i.e. $g = 0$ – no dual labour market structure emerges because there is an asymmetry between workers and firms. Indeed, workers are indifferent between the two types of jobs at wage v but firms are not indifferent to the workers' type since the training cost increases with x. We must assume in this case that firms are able to identify workers' type in order to select only the most able ones.

[3] The role of this assumption will be discussed later. Notice, however, that strategic wage-setting in the primary market will dramatically affect firms' incentives.

Notice, however, that sharing the training cost leads to the workers' self-selection, thereby dispensing with the need of the firm to screen them.

3 The second stage: Cournot subgames

It follows from section 2 that adopting the new technology N in the first stage has two main implications for competition in the second: it allows the firm to benefit from a higher marginal product and it changes the firm's cost structure. Indeed, since the wage in the primary sector must rise in order to attract more (and thus less able) workers, the wage bill and the part of the training cost borne by the firm are now both marginally increasing with the output level. In other words, *choosing N in the first stage yields an increasing marginal cost in the second stage.* Furthermore, the choice of S implies a lower marginal product of labour but a constant marginal cost since no training cost is required, allowing firms to hire workers from the secondary labour market at wage v. Consequently, when considering the adoption of technology N, *firms face a trade-off between marginal product of labour and costs' structure.* Observe that the rival's choice exerts a negative externality since the wage pressure is greater when the two firms are active in the primary sector, thereby increasing marginal cost levels.

As usual, to study the technological choice by firms, we solve the two-stage game by backward induction. Let us thus start with the Cournot subgames.

There are three possible Cournot subgames depending on whether one, two or none of the firms has chosen the technology N. Since marginal productivity of labour is constant, we can express output as a direct function of labour input. If we denote by l_i the labour input in firm i, we can summarise firms' payoffs in the second stage as follows.

Subgame (S, S): *both firms choose the standard technology.*
We have a standard symmetric Cournot game with constant marginal cost. Therefore, the two firms face the following payoff function:

$$\pi_i = l_i(1 - l_i - l_j) - vl_i \qquad i, j = 1, 2$$

Firms' best replies are symmetric and given by:

$$l_i = \frac{1 - v - l_j}{2} \qquad i = 1, 2$$

and it is easily checked that the Nash equilibrium quantity is equal to:

$$l_1^{SS} = l_2^{SS} = \frac{1 - v}{3} \tag{12.4}$$

with payoffs

$$\pi_1^{SS} = \pi_2^{SS} = \left(\frac{1-v}{3}\right)^2 \tag{12.5}$$

Subgame (*N*, *S*): *one firm chooses the standard technology and the other the new one.*
By convention let firm 1 choose the new technology N and firm 2 the standard one S. Using (12.2) and (12.3a), we obtain the following payoffs:

$$\pi_1 = al_1(1 - al_1 - l_2) - (v + agl_1)l_1 - \frac{a}{2}(1-g)(l_1)^2$$

$$\pi_2 = l_2(1 - al_1 - l_2) - vl_2$$

The best replies are therefore given by:

$$l_1 = \frac{a - v - al_2}{a(2a+g+1)}, \qquad l_2 = \frac{1 - v - l_1}{2}$$

and the Nash equilibrium labour demands are equal to:

$$l_1^{NS} = \frac{a(1+v) - 2v}{a(3a+2g+2)}, \qquad l_2^{NS} = \frac{1 + a(1-2v) - g(1-v)}{3a+2g+2} \tag{12.6}$$

The payoffs functions are:

$$\pi_1^{NS} = \left(\frac{1+2a+g}{2a}\right)\left[\frac{a(1+v)-2v}{3a+2g+2}\right]^2 \tag{12.7a}$$

$$\pi_2^{NS} = \left[\frac{1+a(1-2v)-g(1-v)}{3a+2g+2}\right]^2 \tag{12.7b}$$

Subgame (*N*, *N*): *both firms choose the new technology.*
Using (12.2) and (12.3b) we characterise firms' symmetric payoffs as follows:

$$\pi_i = al_i(1 - al_i - al_j) - [v + ag(l_i + l_j)]l_i - \frac{a}{2}(1-g)(l_i + l_j)l_i$$

$$i, j = 1, 2$$

Firms' best replies are symmetric and given by:

$$l_i = \frac{2(a-v) - a(2a+g+1)l_j}{2a(2a+g+1)}$$

Table 12.1 *The second-stage payoff matrix*

	N	S
N	(π_1^{NN}, π_2^{NN})	(π_1^{NS}, π_2^{NS})
S	(π_1^{SN}, π_2^{SN})	(π_1^{SS}, π_2^{SS})

The Nash equilibrium quantities and profit are respectively equal to:

$$l_1^{NN} = l_2^{NN} = \frac{2(a-v)}{3a(2a+g+1)} \tag{12.8}$$

$$\pi_1^{NN} = \pi_2^{NN} = \frac{2}{a}\left[\frac{a-v}{3(2a+g+1)}\right]^2 \tag{12.9}$$

By symmetry $\pi_i^{NS} = \pi_i^{SN}$, $i = 1,2$ and table 12.1 thus summarises the Cournot equilibrium payoffs in the four possible subgames.

The following comments are in order here. First, the main implication of technological choices in the Cournot game is captured by their effects on marginal costs for a firm choosing N. They are given by the following expressions in subgames (N, S), (N, N), respectively:[4]

$$mc_1(NS) = \frac{v + (1+g)\, q_1}{a} \tag{12.10}$$

$$mc_i(NN) = \frac{v}{a} + \frac{1+g}{2a} q_j + \frac{1+g}{a} q_i \qquad i, j = 1,2 \tag{12.11}$$

Observe that the slope of the marginal cost does not depend on whether one or two firms uses the technology, but the value of the intercept does. *This is the externality coming from the labour market.* Inspection of (12.10) and (12.11) reveals that adopting the new technology implies an increasing marginal cost, however training costs are shared between the firms and the workers. Note that the larger the part of the training cost borne by the workers the steeper the marginal cost. This might seem surprising at first glance since a higher g lowers the part of training cost borne by the firm but since workers' training costs increase, a higher wage is required at the margin to attract an additional worker. We thus observe a (negative) training cost effect and a (positive) wage-bill effect. Since we have assumed

[4] Remember that in subgame (N, S) by convention firm 1 chooses the new technology N and firm 2 the standard one S.

that firms were not allowed to discriminate in gross wages, it is quite intuitive to understand that this second effect dominates the first.[5]

Second, the (N, S) subgame deserves special attention. Indeed, since only firm 1 has adopted the new technology, *the two firms compete in quantities under different cost structures*. Therefore we cannot ensure *a priori* that both firms will be active in equilibrium. It could indeed happen that N is a drastic innovation. In the present setting, a 'drastic innovation' is defined as an innovation such that only firm N is active in equilibrium, enjoying the associated monopoly profits. Computations indicate that the condition for a non-drastic innovation is that:

$$a(1 - 2v) + 1 + g(1 - v) > 0$$

Therefore, whenever $v \leq 1/2$ the condition for a non-drastic innovation is automatically fulfilled. When $v > 1/2$, the condition is:

$$1 < a < \frac{1 + g(1 - v)}{2v - 1}$$

Thus, for a large enough, the S firm is pulled out of the industry. Restricting our analysis to non-drastic innovations and thus assuming that $v \leq 1/2$ in the sequel, it is interesting to compare output and profit levels in equilibrium. Straightforward computations indicate that $q_1^* > q_2^*$ if and only if:

$$a > \frac{1 + g + v(2 + g)}{3v} > 1$$

In other words, in order for the N firm to produce more than the S firm in equilibrium, a must be high enough. Therefore, for relatively low values of a the N firm is dominated at the Cournot equilibrium. Correspondingly, it is possible to show (numerically) that in the asymmetric Cournot game, a must be large enough in order to ensure that the N firm captures higher profits than the S one in equilibrium. However, the larger g, the more likely it is that the adoption of the new technology N generates competitive advantage. These results are quite intuitive. Indeed, since firms face different cost structures – i.e. firm 1 faces a marginal cost equal to $(v + (1 + g)\, q_1)/a$ while firm 2's marginal cost is v, firm 1 benefits from a marginal cost advantage only for relatively low output levels – i.e. for $q_1 < v(a - 1)/(1 + g)$. This explains why a technology which

[5] Observe from (12.9) that when both firms adopt the new technology, their payoffs depend negatively on g. Therefore, in our example, firms could be inclined to bear all the training cost.

increases labour productivity is not necessarily more profitable. The labour market parameters are thus crucial here. We summarise our findings in proposition 1.

Proposition 1: When adoption involves a specific training cost, adopting the new technology does not imply competitive advantage in equilibrium.

4 Technological choices

Before we study the first stage of our game, it is useful to consider the extreme case in which the new technology does not require specific training cost – i.e. the labour cost is invariably given by v. Since we have assumed that the technology N is freely available, it is clear that both firms will always choose technology N in a subgame perfect equilibrium (SPE). In other words, as long as the adoption of the technology does not affect the labour market, both firms adopt it. However, we will show now that the existence of a specific training cost in the primary sector may lead to heterogeneous technological choices.

Let us now analyse the first stage in which firms choose the type of technology (strategies N, or S). The payoffs matrix of this game is derived from the equilibrium of the different subgames solved in section 3 and summarised by table 12.1. In order to characterise the equilibrium[6] in the first-stage of the game, we characterise firms' best replies and concentrate on non-drastic innovations. It is indeed obvious that if the innovation is drastic, both firms will adopt it. Using table 12.1, the problem can be summarised as follows:

- If firm j chooses the technology S, the best reply for firm i is S if and only if:

$$\left(\frac{1-v}{3}\right)^2 \geq \left(\frac{1+2a+g}{2a}\right)\left[\frac{a(1+v)-2v}{3a+2g+2}\right]^2 \tag{12.12}$$

- If firm j chooses the technology N, the best reply for firm i is N if and only if

$$\frac{2}{a}\left[\frac{a-v}{3(2a+g+1)}\right]^2 \geq \left[\frac{1+a(1-2v)-g(1-v)}{3a+2g+2}\right]^2 \tag{12.13}$$

Observe that (12.12) is a polynomial expression of degree 3 whose analytical solution turns out to be quite messy. Equation (12.13) is a

[6] We concentrate exclusively on pure strategy equilibria.

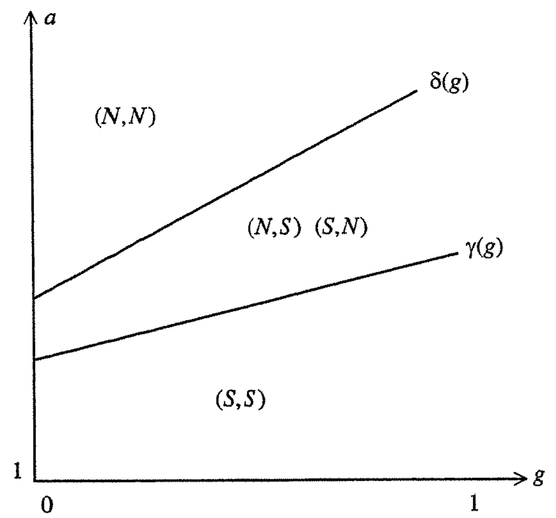

Figure 12.1 A representative partition of the (a, g) space according to the nature of SPE

polynomial expression of degree 5 for which no analytical solution can be found. We have therefore performed numerical computations using the *Mathematica* Software in order to solve the problem. Observe, however, that all rational functions entering in both equations are well defined continuous functions in the relevant parameters' constellations – i.e. for $a > 1$, $v < 1$ and $g \in [0, 1]$. We can therefore rely on the results of our numerical computations.[7]

For any given value of the market-clearing wage $v \leq 1/2$, we have identified two functions, $\gamma(g)$ and $\delta(g)$ which characterise the solution in a of (12.12) and (12.13), respectively. Figure 12.1 summarises the results of our numerical computations by plotting the functions $\gamma(g)$ and $\delta(g)$ for some fixed level of v.

- When $a < \gamma(g)$, S is a best reply against S
- When $a > \delta(g)$, N is a best reply against N
- When $a \in [\gamma(g), \delta(g)]$, N is a best reply against S and S is a best reply against N.

It follows that for $a \in [1, \gamma(g)]$, (S, S) is the unique SPE. When $a \in [\gamma(g), \delta(g)]$, we have two SPEs involving only one firm adopting the

[7] Under the assumption that $v \leq 1/2$, these functions are in fact monotone in the relevant domain of $a > 1$ and $g \in [0, 1]$.

new technology. Finally for $a > \delta(g)$, we have a unique SPE in which both firms adopt the new technology.

Note that the interval $[\gamma(g), \delta(g)]$ is never empty. Therefore, we always end up with a partition of the (a, g) space into three regions, each of them corresponding to one of our three possible SPE outcomes. Computations also indicate that $\delta(g) - \gamma(g)$ is increasing in g.

Proposition 2: We obtain the following result that does not depend on the way firms and workers share the training cost.

- When the productivity gain is small, none of the firm adopts technology N in an SPE
- When the productivity gain is large, the two firms adopt technology N in an SPE
- For intermediate values of the productivity gain, one firm only adopts technology N.

Proposition 2 establishes that, even in the absence of patent protection or licence fees, a process innovation may not be adopted by all firms within a given industry. This may thus explain endogenously technological heterogeneity. This result proceeds first from the idea that the adoption of a new technology tends to carry with it an adjustment of the labour force: the matching between skills' requirements associated with the innovation and skill availability in the labour market becomes central. It is indeed obvious that a technology whose skill requirements are much above existing standards in the labour market is not very likely to be adopted, simply because the training costs involved would be too high. This provides a first and direct link between labour markets and technology adoption. However, it hardly explains heterogeneous choices by the firms. This is where strategic considerations comes into play. Indeed, in an oligopolistic industry, the attractiveness of an innovation process will depend on rivals' choices. In the present analysis, the labour market exerts a negative externality. Indeed, once a firm has chosen the new technology, this technology becomes less attractive to the other because of a labour cost effect. Once a firm has adopted the new technology, it may be optimal to the other firm to choose S because it would otherwise imply a higher pressure in the primary labour market, thereby pushing wages and thus production costs up. Clearly, the rise in marginal productivity of labour has to be large enough in order to sustain a symmetric (N, N) equilibrium – i.e. to overcome the negative externality. Moreover, since quantities are strategic substitutes, choosing technology S may allow the firm to benefit from the less aggressive behaviour of the N firm, which is facing increasing marginal cost. This argument is best illustrated by the fact that in an asymmetric equilibrium, the S firm may be the dominant one. It also follows that if firms were to choose technologies in sequence – i.e. in a Stackelberg-like framework – the first-mover advantage could take the form of a non-adoption.

Clearly, our result bears some resemblance to that of Mills and Smith (1996) since they also conclude with heterogeneous choices of technologies as possible equilibrium outcomes. However, one major difference has to be underlined. In their paper, the relative attractiveness of the different technologies depends exclusively on their influence for the competition in the product market since associated costs are exogenously given. In the present analysis, the relative attractiveness of the new technology is endogenous to the firms' choices owing to the explicit treatment of the labour market.

5 Discussion

In section 4, we have shown by means of an example that, when firms take into account the effects of technological progress on labour market equilibrium, they could be led to choose different technologies although they face *ex ante* a completely symmetric opportunity set. Admittedly, the model we have considered relies on very specific assumptions. It is therefore important to evaluate the robustness of our conclusions in more general settings.

Let us first discuss the relevance of training costs as the central argument governing labour market behaviour. Although this seems quite natural in a context of new technologies, it should be clear that a similar argument can apply to any context in which technological choices are associated with specific, thin, labour markets. Indeed, what is basically required for our result is a finitely elastic labour supply, so that a firm faces an increasing marginal cost. Second, the training sequence we consider is rather special. Indeed, in our static framework, it is implicitly assumed that training and production are taking place simultaneously. It is perhaps more intuitive to assume that production takes place after some training period. In this case, adopting the new technology will amount to bearing first a training cost, which depends on the number of workers hired and can be viewed as a sunk cost afterwards, and facing a constant marginal cost of production corresponding to the wage level. Note, then, that this does not preclude the existence of heterogeneous choices. Indeed, the labour market still exerts a negative externality since the level of the (fixed) training cost depends on the aggregate labour demand and thus on rivals' choices. More fundamentally, this would affect the conditions of competition in the second stage. Indeed, the numbers of workers trained will determine the production capacities in the Cournot game, so that product competition takes place under limited production capacities.

Another limitation of the model is that the wage in the primary sector is set according to a Walrasian mechanism. Since at most two firms operate in this market, it seems natural to consider that these firms enjoy some market power. Doing this would raise very serious technical problems – in particular, the existence of an equilibrium in wages may be highly problematic, especially when both firms are active in the primary market. When the two firms are active in the primary market, a Bertrand-like competition is likely to be observed. Since workers maximise net wages and firms require identical training, a slight differential is sufficient for one firm to capture all workers – or, more precisely, to enjoy the possibility of choosing among the entire set of applicants at this wage. Firms could therefore enter in a upper-bidding process. It is clear, however, that defining a wage equilibrium in this case is quite problematic. Indeed, wages determine the labour supply addressed to each firm, and thereby production capacities. A game where firms choose wages and quantities simultaneously would face first a definition problem – indeed, the strategies in the quantity game would be contingent on the wage schedule, since this would determine maximal outputs. Let us assume then that firms set wages and quantities sequentially. This amounts to considering a two-stage game in which firms name wages, hire workers and train them in the first stage and compete in quantities in the second. Let us assume that firms cannot fire workers in the second period. Thus, all costs are borne in the first stage and are irrelevant in the second. Characterising an SPE of this game is not easy. An outcome of the first stage consists in a vector of wages and labour force for each firm. Any such outcome defines a very simple game at the second stage where firms are Cournot competitors facing a limited production capacity. Unfortunately, the first stage of the game is not so simple. Recall that workers allocate their labour unit by comparing net wages. If wages are equal they are indifferent between the two firms, otherwise they apply to the high-wage firm. However, it is not obvious that this firm should hire all applicants so that some applicants can be rationed and may be willing to accept a position in the low-wage firm. Choosing a wage slightly above the rival's, allows a firm – say, firm 1 – to capture the whole labour supply in the primary market. Either firm 1 hires all applicants, which implies that production capacity of firm 2 is zero in the Cournot game, or firm 1 hires only part of the applicants and obviously the one exhibiting the lowest training costs. Note, then, that increasing the wage above the other's has two implications. First it allows the firm to pre-empt the market completely, but it also allows the firm to select among the applicants the most able ones, in which case firm 2's output is determined by the residual supply addressed to her after firm 1 has hired all the workers it wants. A wage increase may in fact therefore, result in a lower cost. Thus, although it seems intuitive that an equilibrium should involve equal wages, the existence of such an equilibrium is not guaranteed. Consider an equilibrium candidate with equal wages set at a level which determines the aggregate labour supply required for producing the symmetric Cournot equilibrium outputs. Raising the wage slightly above the other's is clearly profitable simply because it allows the firm to benefit from lower cost associated with the possibility of choosing the most able applicants.

In view of the preceding remarks, it is worth discussing alternative frameworks for modelling product market competition. In this respect our results largely depend on the assumption that firms set quantities instead of prices. Indeed, in the present framework, the adoption of the new technology yields increasing marginal costs, and it is well known that the existence of a pure strategy equilibrium in prices is problematic in this case. Note that if firms were to hire workers before price competition takes place, a similar problem would arise since firms would then face limited production capacities as a function of their labour force. What makes the problem serious is that if on the one hand a pure strategy equilibrium does not exist, on the other payoffs associated with a mixed strategy equilibrium will be above the Bertrand ones. Thus, firms would be inclined to adopt the new technology because the resulting changes in the labour market translate into quantitative restrictions in the product market. Firms have a clear incentive to adopt the new technology, since it has the desirable implication of relaxing price competition. More generally, under price competition, firms could be tempted to use the labour market strategically, in order to achieve more collusive outcomes. Technological choices could be viewed as commitments to particular cost functions (see Vives, 1986). These choices are then governed by their strategic implications for product market competition and equilibrium outcomes are likely to be viewed as less competitive.

6 Concluding remarks

In this chapter, we have considered an example where the structure of the labour market affects firms' technological choices. The adoption of a new technology involves an adjustment of workers' skills which essentially translates into an increasing marginal cost. The labour market entails a negative externality because a firm's incentive to adopt the new technology depends on the shape of the resulting cost function, which in turn depends on the other firms' choices. In this context, firms may be led to choose different technologies in equilibrium – i.e. in equilibrium not all firms adopt the new technology. The present chapter can be viewed as a modest attempt to introduce labour market components in the analysis of oligopolistic industries. In this respect, we have shown that the structure of the labour market may have very important implications: in particular, it directly affects the degree of competition in the product market. Even though we have stressed that generalisations should not be expected to be easy, we believe that this topic deserves to be investigated further.

Bibliography

Bénassy, J.P. (1989) Market size and substitutability in imperfect competition: a Bertrand–Edgeworth–Chamberlin model, *Review of Economic Studies*, 56, pp. 217–34

Burda, M. (1988) Wait unemployment, *Economic Policy*, 7, pp. 393–425

Gabszewicz, J. and A. Turrini (2000) Workers' skills, product quality and industry equilibrium, *International Journal of Industrial Organization*, 18, pp. 575–93

Horn, H. and A. Wolinsky (1988) Bilateral monopolies and incentives for merger, *Rand Journal of Economics*, 19, pp. 408–19

Mills, D.E. and W. Smith (1996) It pays to be different: endogenous heterogeneity of firms in an oligopoly, *International Journal of Industrial Organization*, 14, pp. 317–29

Phlips, L. (1995) *Competition Policy: a Game-Theoretic Perspective*, Cambridge: Cambridge University Press

Reinganum, J. (1989) The timing of innovation: research, development, and diffusion, chapter 14 in R. Schmalensee and R.D. Willig (eds.), *Handbook of Industrial Organization*, 1, Amsterdam: North-Holland, pp. 849–908

Saint-Paul, E. (1996) *Dual Labor Markets: A Macroeconomic Perspective*, Cambridge, Mass.: MIT Press

Vives, X. (1986) Commitment, flexibility and market outcomes, *International Journal of Industrial Organization*, 4, pp. 217–29

Wauthy, X. and Y. Zenou (1997) Dual labor markets, efficiency wages and labour heterogeneity, *CORE Discussion Paper*, 9772

Ulph A.M. and D.T. Ulph (1994) Labor markets and innovation: *ex post* bargaining, *European Economic Review*, 38, pp. 195–210