On The Role of Spillover Effects in Technology Adoption Problems

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Abstract

This paper examines, in an efficiency wages setting, the technology adoption problem faced by a firm. It is shown that the adoption of new technologies may be delayed, or even that it does not take place, for firms which are price makers on the labour market. A general result of inefficient technology adoption is derived. This result follows from the impact of technology induced spillovers effects on workers' reservation utility. Better technologies determine higher reservation utility levels and this, in turn, implies that the firm must pay higher wages in order for the participation and the incentive constraints of workers to be satisfied.

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1 Introduction

Why countries do not all adopt the best available technologies? Why not all countries use technology to promote economic progress? Technology is certainly among the most relevant growth engines, but not all countries use it to become richer. Recent empirical studies show that there are significant differences in output levels and these differences seem to be persistent (e.g. Maddison [1995], Ben-David [1994], Sala-i-Martin [1994]). Though superior technologies are available and can be purchased elsewhere, many poor countries use inferior technologies and often do it inefficiently.

This, as noted by Lucas [1990] contradicts economic theory, especially in a world characterized by high capital mobility.

Most of the models studying the technology adoption problem, justify the adoption of different technologies in different countries emphasizing the role of transfer and adjustment costs (e.g. Jovanovic and Lach [1989], Parente and Prescott [1994], Grossman and Helpman [1991, chpts. 6 and 11], Anant, Dinapoulos and Segerstrom [1990], Barro and Sala-i-Martin [1997]). There are however models assuming that the knowledge of a technology spreads instantaneously and that there are not direct costs related to its adoption. Under these assumptions, Basu and Weil [1998] state that a superior technology will not be adopted if the economy is not developed enough, while Zeira [1998] shows that the adoption of different technologies in different countries is related to the prices of factors of production and to the increasing quantity of capital required by technological progress.

Finally, the recent empirical literature focuses on the role of exogenous factors such as the available resources and infrastructures and the political regime (e.g. Sachs and Warner [1997], Hall and Jones [1997] and Sala-i-Martin [1997]).

The argument of our paper is instead related to an element usually not emphasized in the literature, but widely supported at the empirical level: the fact that monopolistic power is much more diffused in poor countries than it is in rich and developed countries. It seems therefore natural to ask if there are some relationships, between market power and technology adoption processes, that impede the adoption of superior technologies instead of favoring it. Our claim is that the presence of monopolistic power on factors markets can slow down the adoption of superior technologies and thus technical progress. Such a view is definitely not new. It dates back to the Classics and it is central both in A. Smith's and A. Marshall's thought.

In a recent paper, Parente and Prescott [1999] emphasize the importance of this factor in blocking the adoption of superior technologies. They focus on the role of monopolistic agreements and they show that the existence of a coalition of labor suppliers, selling their input under monopolistic conditions to all firms, can prevent the entry in the industry of other coalitions having access to a superior technology, but over which the original coalition does not have monopoly rights, blocking therefore the adoption of a superior technology.

Our claim, instead, is that the presence of monopolistic power on the labor market in itself can impede economic progress and drive the adoption of inefficient technologies, even in the absence of coalitions or forms of coordination on the labor market.

The model we introduce studies a small economy, characterized by the presence of the subsistence sector and only one industry, in which it operates only one price taker firm, selling its good on the international market. However, the firm has monopolistic power on the labor market and, given technology, labor is the only input of the production function. For simplicity, we assume that it is impossible for other firms to enter the industry[1]. This implies that workers can not transform in entrepreneurs even when the adoption costs of technology are nihil. Workers can therefore be in one of two situations: they are employed at the firm, or they are unemployed (since there are not other employer available). When unemployed, workers receive their subsistence means from the subsistence sector.

We focus on the decision of the firm to adopt a superior technology[2]. On the one hand, assuming that the introduction of a new technology does not affect the demand for the good produced, the firm should observe an increase in its profits. On the other hand,the adoption of a superior technology may imply that employed workers can learn the technology just by using it. In other words, the adoption of a new technology induces an increase in the human capital level of employed workers, through a learning process, which we assume to be instantaneous. We do not model the nature of this learning process: it can be some sort of learning by doing or specific instruction. As far as this learning process increases the level of workers' general human capital, it seems natural to assume that workers will be able to put at work the increase in their human capital in the subsistence sector, both using it directly or transmitting it to unemployed workers. This, in turn, increases the productivity of workers in the subsistence sector and thus their

[1] This impossibility can be due to institutional constraints (e.g. the distribution of property rights and imperfections of financial markets), as well as to the absence of infrastructures, or to the relevance of political variables (like the presence of political instability or dictatorships), which make the entry of competitors impossible or unprofitable.

[2] In example, by assuming that the firm operates a form of large-scale agriculture and that the barriers to entry are induced by the allocation of property rights on the land, the introduction of genetic manipulation's techniques, which reduce the amount of labor needed in cultivating land, would be a superior technology with respect to traditional methods.

reservation wages and their bargaining power[3]. In other words, the adoption of a superior technology generates spillover effects, which increase the reservation utility of workers. The firm is therefore forced to offer higher wages to workers, if it wants them to accept its offer and exert the desired effort once employed . The associated increase in costs can be enough to induce the firm not to adopt a superior technology[4].

The channel through which monopolistic power on the labor market can block technological progress is, therefore, a strategic one. It depends on the relationship between the reservation utility of workers and the technology adopted by the firm, via the technology induced spillover effects. Such spillovers are in the form of transferable human capital and they originate from the worker's ability to manage a certain technology. The training in such technology is a cost for the firm which can not be transferred to workers or on the good price (due to the price taking assumption). On the other hand, by learning it, workers acquire better skills and increase their level of knowledge which, in turn, increase the value of their outside option[5].

The relevance of this kind of spillovers, and their impact on wages, is widely supported by the empirical literature (e.g. Nadiri [1993][6]), which stresses that the knowledge of a technology (and the skills necessary to implement it) is very costly to be produced, but very easy to be reproduced and emphasizes that firms are typically unable to appropriate all benefits deriving from the technological innovations they introduce.

The formal structure of our model is that of efficiency wage models à la

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[3] More generally, the improvement in workers' human capital may increase their bargaining power, in example, through the organization in unions. In other words, technology generates spillover effects from the industry to the subsistence sector.

[4] If both the firm and the workers are perfectly informed about the advantages and the costs associated to the adoption, then they can design bargaining procedures to allocate and distribute the net gains from the adoption of a better technology. However, workers have an incentive to bind themselves in a credible way to the agreements signed with the firm only if the wages they receive are high enough to cover their participation and incentive compatibility constraints. Otherwise workers will try to take advantage from the available outside options.

[5] For a systematic and complete survey of the human capital literature see Booth and Snower [1995].

[6] Nadiri [1993] contains an extensive survey of the literature investigating spillover effects induced by the adoption of superior technologies. Other papers have studied the impact of spillovers on wages (e.g. Schultz [1975], Bartel-Lichtenberg [1987 and 1991], Acemoglu [1998] and Machin and Van Reenen [1998] investigate the relationships between adopted technologies, R&D activities and wages, while Goldin and Margo [1992], Katz and Murphy [1992] and Autor, Katz and Krueger [1998] analyze wage differentials and the behavior of skilled and unskilled labor demand).

Shapiro and Stiglitz [1984]. However, in our model the participation constraint of workers is endogenous in the choice of technology and therefore it can not be taken as satisfied by assumption. It is exactly this endogeneity to generate the main result of the paper, i.e. the possibility of inefficient technology adoption. Moreover, as in Shapiro and Stiglitz, and for the same reasons, we get involuntary unemployment in equilibrium.

The paper is organized as following. The second section introduces the economy and it investigates the labor market and workers' decisional problem. The third section focuses on the firm's problem and a result of inefficient technology adoption is derived. The fourth section determines the equilibrium level of employment and the wage. Concluding remarks and future research are discussed in the last section.

2 The labor market

There are N identical workers and, at any point in time, each of them can be either employed by the firm or unemployed. In the latter case we consider the worker as self-employed in the subsistence sector. In order to eliminate the heterogeneity between employed and unemployed workers, we assume that once a superior technology has been introduced, the knowledge associated to it diffuses instantaneously[7].

As in Shapiro and Stiglitz [1984], each worker receives positive utility from consumption and he finds costly to exert effort. We assume that the instantaneous utility function is separable and that workers are risk neutral, i.e.

$$U\left(w,e,T\right)=w-v\left(e\right)+\gamma\pi\left(L,T\right),$$

where w is the wage, $v(e)$ is a function representing the disutility of effort and $\gamma\pi\left(L,T\right)$ is the quota of the firm's profits going to each worker. Assuming that

[7] We might also have assumed the presence of a union (or of institutional constraints) able to link wages to the technology adopted and not to individual skills. If the firm does not have the opportunity to pay lower wages to the never-employed-workers, the heterogeneity among skilled and unskilled workers disappears, even though there is still heterogeneity between the workers employed and the ones unemployed.

Notice that there is still heterogeneity between shirkers and not-shirkers, as in the standard efficiency wages models. In this paper we treat this heterogeneity in the standard way, although in a more elaborate version of the model, the decision to shirk or not to shirk of a worker: it is in fact possible that a non-shirker worker can learn the technology faster and in a better way than a shirker,benefiting more of the spillover effects induced by technology. This makes a shirking behavior more costly and contribute to relax the incentive compatibility constraint the wage offered by the firm must satisfy.

the firm is owned by a benevolent social planner and that profits are equally distributed to all agents in the economy[8], it is $\gamma = \frac{1}{N}$. We will maintain this assumption throughout the paper.

We assume for analytical simplicity that the disutility of effort can take only one of two values $v(0) = 0$, when the worker exerts no effort, and $v(\overline{e}) = \overline{v} > 0$, when the worker exerts the level of effort required by the firm, i.e. when he does not shirk. Each worker not exerting any effort while working for the firm is subject to a probability c, $0 \leq c \leq 1$, of being caught shirking by the firm, in which case he (she) is fired[9]. Once a worker has been fired, the probability to be re-hired determines the length of the unemployment phase. Since technology is labor saving, when superior technologies are adopted the number of employed workers tends to diminish (given output). It is therefore easier for the firm to hire the needed labor force and it is more difficult for a fired worker to be re-hired. Again for simplicity, we assume that the probability to be re-hired is equal to zero. Finally, we assume that the probability to leave or loose the job for exogenous reasons (i.e. when not shirking) is equal to zero as well[10]. If unemployed an individual obtains utility $\overline{U}(T)$ in the subsistence sector of the economy. Notice that this reservation utility is a function of the technology adopted by the firm. We let $\overline{U}'(T) > 0$. That is, we assume that the reservation utility is an increasing function in technology, due to the positive spillover effects associated to technology adoption process.

In order to confirm that $U(w, e, T)$ and $\overline{U}(T)$ are based on the primitives of the economy and modeled in a coherent way, we may think that both the disutility of effort (both when an agent is employed by the firm and when unemployed) and the reservation utility are functions of the level of knowledge of agents. Furthermore, it seems reasonable to assume that knowledge is an increasing function of the technology adopted by the firm, which allows us to write both the disutility of effort and the reservation utility as functions of the technology adopted by the

[8] This is only one of many possible profits distribution schemes, but it has the advantage of making possible comparisons between the firm problem and the planner problem, which will be introduced later. It is worth noticing that such a distribution scheme has the advantage to simplify the analysis.

[9] We assume here that the probability c is given exogenously. Such an assumption can be easily relaxed by letting c be a function of the technology adopted by the firm. However, if it easy to recognize the existence of a relationship between the adopted technology and c, it is much more difficult to find out its significance and impact. Moreover, it is possible to further endogenize c, as suggested by Shapiro and Stiglitz, devising ways for the firm and workers to exchange stricter monitoring (obviously costly for the firm) with higher wages.

[10] This is again a simplifying assumption. However, our conclusions do not change by introducing a positive probability to loose the job.

firm. Since in the basic model we have assumed that the disutility of effort can take only one of two values $(0, \overline{v})$, we do not model explicitly the relationship between technology and disutility of effort. On the other hand, it seems reasonable to assume that the reservation utility is an increasing function of knowledge (and therefore of technology), which explains why we have directly written $\overline{U}(.)$ as an increasing function of T [11].

Workers maximize their utility by solving a decisional problem with respect to the effort level. As in Shapiro and Stiglitz's model, they compare the levels of their expected utility when exerting effort and when not exerting effort. However, while in Shapiro and Stiglitz the model is set in continuous time, we can limit our attention to the static problem, given that we assume the probability to loose the job and the probability to be re-hired once fired equal to zero. We denote with V^{NS} and V^{S} respectively a worker's utility being a non shirker and a shirker:

$$V^{NS} = w - \overline{v} + \frac{1}{N}\pi(L, T),$$

$$V^{S} = (1-c)\, w + (1-c)\frac{1}{N}\pi(L, T) + c\left[\overline{U}(T) + \frac{1}{N}\pi(L, T)\right].$$

Workers will not shirk if and only if

$$V^{NS} \geq V^{S},$$

which, after some algebraic manipulations, leads to

$$w \geq \overline{U}(T) + \frac{1}{c}\overline{v},$$

i.e.

$$\frac{c}{1-c}\left[V^{S} - \overline{U}(T)\right] \geq \overline{v}. \qquad (1)$$

From expression (1), it follows immediately that, in the absence of a credible punishment phase following shirking, all workers have an incentive to shirk. In particular, if $V^{S} = \overline{U}(T)$, constraint (1) can never be satisfied.

In our model the decision on the level of effort depends crucially on the technology adopted by the firm. Let $\widehat{w}(T) = \overline{U}(T) + \frac{1}{c}\overline{v}$. Workers do not shirk if the

[11] Notice that the analysis does not change if we take into account explicitly the relationship between disutility of effort and technology, provided that we make the assumption that the adoption of superior technologies decreases the disutility of effort.

wage paid by the firm is at least equal to the reservation wage $\widehat{w}(T)$, which is the minimum wage that must be paid in order to induce a worker to exert effort. It is straightforward to observe that $\widehat{w}(T)$ is increasing in the expected utility of the unemployed worker. The latter, in turn, is increasing in the technology adopted by the firm. This clarifies the role of technological innovation in making endogenously binding the participation constraint of workers.[12]

3 The firm's problem

The production sector is composed by only one industry in which it operates only one firm, price taker on the good market and price maker on the labor market. The firm's production function is $F(L,T)$, where T is the technology adopted by the firm and L the labor used when the adopted technology is T. In this model technology enters the production function exactly as capital in standard models. However, it may be useful to think at technology in a broader sense, incorporating in it the firm's organizational processes or the management's characteristics. Notice also that the amount of labor used by the firm depends in equilibrium by the technology adopted. Technological progress is of a labor saving type, in the sense that superior technologies increase the productivity of labor.

More precisely, we assume $\frac{\partial F(L,T)}{\partial T} > 0$, $\frac{\partial F(L,T)}{\partial L} > 0$ and $\frac{\partial^2 F(L,T)}{\partial L^2} < 0$. Given that labor is the only input in the production function apart from technology, the assumption that $\frac{\partial F(L,T)}{\partial T} > 0$ is sufficient to guarantee that technological progress is labor saving, i.e. $\frac{\partial^2 F(L,T)}{\partial L \partial T} > 0$.

The firm's decisional problem amounts to decide which technology to adopt

[12] Shapiro and Stiglitz's observations remain valid in our context. In particular, $\widehat{w}$ increases when the level of effort $\overline{e}$ exerted by a worker increases and when the probability c he (she) is detected shirking decreases.

The bigger c, the bigger $\frac{c}{1-c}$ and therefore the lower the premium, $(V^S - \overline{U}(T))$, needed to induce a worker not to shirk. Notice however that V^S is a function of c. By defining $\varphi(c) = V^S - \overline{U}(T)$ and by using De L'Hopital's theorem we have:

$$\lim_{c \to 1} \frac{c}{1-c} \varphi(c) = w - \overline{U}(T) > 0$$

and

$$\lim_{c \to 0} \frac{c}{1-c} \varphi(c) = 0 < \overline{v}.$$

Therefore it must exist a value $\underline{c}$ such that if $c < \underline{c}$ the no shirking constraint (1) is never satisfied and if $c > \underline{c}$ it is always satisfied.

between the available technologies, as defined in the closed interval $[0, T_{MAX}]$, $T_{MAX} > 0$, where they are indexed and ranked by their efficiency. That is, $T = 0$ denotes the worst technology and $T = T_{MAX}$ the best one. We assume that there are no direct adoption costs associated to technology and we do not model explicitly the market of technology. This seems to be without loss of generality given our objective. In fact, the introduction of a price for the technology and of a direct cost associated to the adoption of a superior technology would further reduce the incentives for the firm to adopt it, reinforcing the effects of spillovers.

3.1 The social planner problem

The benchmark to define the best one between the available technologies is given by the first-best solution of a benevolent social planner's decisional problem. We assume that the planner's objective function is an utilitaristic social welfare function. In other words, the planner maximizes the sum of the firm's profits and the utility of all employed and unemployed workers[13]. Therefore its problem can be written as:

$$\underset{T}{Max} \left[pF(L,T) - w\left(L^{NS} + (1-c)L^{S}\right) + (w - \overline{v})L^{NS} + \right.$$

$$\left. + w(1-c)L^{S} + cL^{S}\overline{U}(T) + (N-L)\widetilde{U}\right],$$

where $L = L^{NS} + L^{S}$ and $\left(L^{NS}, L^{S}\right)$ denote respectively the number of shirker and non-shirker workers at any point in time and $\widetilde{U}$ denotes the reservation utility of never-employed workers. Given that we assumed both the probability of being caught shirking and the disutility of effort to be independent of the adopted technology, by letting without loss of generality $\widetilde{U} = 0$, the previous problem can be rewritten equivalently as

$$\underset{T}{Max}\ pF(L,T) + \left(cL^{S}\right)\overline{U}(T).$$

The solution of this problem is

$$\overline{T}(L) = Arg\max_{T}\left\{pF(L,T) + \left(cL^{S}\right)\overline{U}(T)\right\}.$$

Since, for all L, $F(L,T)$ and $\overline{U}(T)$ are monotonically increasing in T (and p is given), $\overline{T}(L)$ is a constant function of L. Therefore, a benevolent social planner, whose objective is to maximize the social welfare function, adopts technology T_{MAX}, i.e. $\overline{T}(L) = T_{MAX}$.

[13] Notice that this is coherent with the profits' distribution scheme we have introduced in section 2.

3.2 Technology adoption and labor demand

The firm's objective is, as usual, the maximization of the profit function. Therefore, it solves the optimization problem:

$$\begin{cases} \underset{L,T}{Max}\ pF(L,T) - wL \\ s.t.\ w - \overline{v} = c\overline{U}(T) + (1-c)w \end{cases}. \tag{2}$$

We will start concentrating on interior solutions, without taking into account the additional constraints $0 \leq L \leq N$ and $0 \leq T \leq T_{MAX}$.

In the firm's decisional problem, and in the social planner's problem as well, we have assumed the price for the good produced by the firm to be exogenously given. We can assume that the price is set by the competition on international markets where the firm is selling its good .

Problem (2) can be solved in two steps. In the first one we maximize the profit function with respect to technology, given L, while in the second step, once we have determined the optimal technology as a function of L, we will solve the problem in L.

By substituting the participation and incentive compatibility constraint into the profit function and by maximizing it with respect to T, given L, we have

$$\underset{T}{Max}\ pF(L,T) - \left(\overline{U}(T) + \frac{\overline{v}}{c}\right)L.$$

The first order condition is

$$p\frac{\partial F(L, T^*(L))}{\partial T} - \overline{U}'(T^*(L))L = 0. \tag{3}$$

In order to guarantee the concavity of the objective function in T, we assume that

$$\overline{U}''(T) > \frac{p}{L}\frac{\partial^2 F(L,T)}{\partial T^2}. \tag{4}$$

Condition (4) requires that the impact of changes in technology on the reservation utility is always greater than the impact on the marginal productivity of technology for the firm[14]. It is straightforward to observe that the objective function is always concave when $\frac{\partial^2 F(L,T)}{\partial T^2} < 0$.

Given the concavity of the objective function, the first order condition (3) is both necessary and sufficient for a maximum of the firm's technology adoption problem, given L.

[14]By using first order condition (3), it is easy to study the sign of $T^*(L)$. Applying the

The following proposition shows that, under the assumptions we made on $F(L,T)$ and $\overline{U}(T)$ and given that $\overline{T}$ is not a function of L, i.e. $\overline{T} = T_{MAX}$, there exists one and only one technology which satisfy condition (3) and is a maximum of (2)[15].

Proposition 3.1

If, $\forall L \in [0, N]$, the assumptions on $F(L,T)$ and $\overline{U}(T)$ (i.e. $F(L,T) \in C^2$, $\frac{\partial F(L,T)}{\partial T} > 0$ and $\overline{U}(T) \in C^2$, $\overline{U}'(T) > 0$), and the following boundary conditions hold:
3.1.1 $k(L)\frac{\partial F(L,T)}{\partial T}\mid_{T=0} > \overline{U}'(T)\mid_{T=0}$, *where* $k = \frac{p}{L}$;
3.1.2 $k(L)\frac{\partial F(L,T)}{\partial T}\mid_{T=T_{MAX}} < \overline{U}'(T)\mid_{T=T_{MAX}}$;
then, $\forall\ L \in [0, N]$, *problem (2) has a unique interior solution* $T^*(L), T^*(L) \in (0, T_{MAX})$.

Proof.
There are four possible cases. When $\frac{\partial^2 F(L,T)}{\partial T^2} < 0$ and $\overline{U}''(T) > 0$ the thesis follows immediately from boundary conditions (3.1.1) and (3.1.2). When $\frac{\partial^2 F(L,T)}{\partial T^2} > 0$ and $\overline{U}''(T) > 0$, both $\frac{\partial F(L,T)}{\partial T}$ and $\overline{U}'(T)$ are increasing functions. By continuity and monotonicity, from conditions (3.1.1) and (3.1.2), it follows that $\frac{\partial F(L,T)}{\partial T}$ and $\overline{U}'(T)$ intersect in the interval $(0, T_{MAX})$ and such intersection is unique. Similarly when $\frac{\partial^2 F(L,T)}{\partial T^2} < 0$ and $\overline{U}''(T) < 0$ both $\frac{\partial F(L,T)}{\partial T}$ and $\overline{U}'(T)$ are decreasing functions and the results follow, again by monotonicity and continuity, if the boundary conditions (3.1.1) and (3.1.2) are satisfied. ■

Figures 1, 2 and 3 provide a graphical representation of proposition (3.1)[16].It is straightforward to observe that whenever conditions (3.1.1) and (3.1.2) are not

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implicit function theorem we get:

$$\frac{dT^*(L)}{dL} = -\frac{p\frac{\partial^2 F(L,T^*(L))}{\partial T \partial L} - U'(T^*(L))}{p\frac{\partial^2 F(L,T^*(L))}{\partial T^2} - U''(T^*(L))L}.$$

Since, given the assumption on the concavity of the objective function, the denominator of the previous expression is always negative, the sign of $\frac{dT^*(L)}{dL}$ depends on the sign of the numerator. In particular, since both $U'(T^*(L))$ and $p\frac{\partial^2 F(L,T^*(L))}{\partial T \partial L}$ are positive, it will be negative whenever $U'(T^*(L)) > p\frac{\partial^2 F(L,T^*(L))}{\partial T \partial L}$.

[15] In section five we discuss an example with specific functional forms.

[16] Notice that in these figures the functions $k(L)\frac{\partial F(L,T)}{\partial T}$ and $\overline{U}'(T)$ are represented as linear functions only for convenience. It needs not necessarily to be the case.

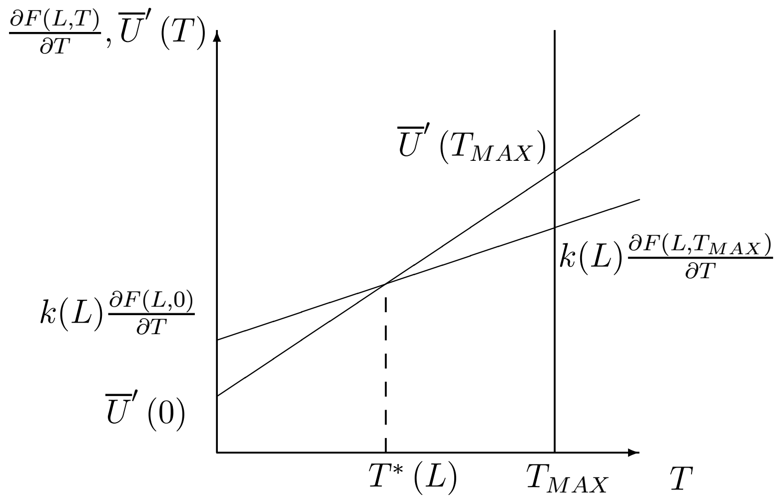

Figure 1: The adoption of an inefficient technology when $\frac{\partial^2 F(L,T)}{\partial T^2} > 0$ and $\overline{U}''(T) > 0$.

satisfied it is possible to reach corner solutions in which the firm might choose the worst technology available (in which case innovations are completely absent), as well as the best technology available (on the technological frontier) T_{MAX}. In particular, the latter will always be the case if $\frac{\partial^2 F(L,T)}{\partial T^2} > 0$ and $\overline{U}''(T) < 0$.

Condition (3.1.1) states that, when starting from very low technologies, the marginal increase in workers' reservation wage is lower than the increase in the marginal productivity of technology, induced by the adoption of the better technology. This seems to be quite intuitive. Consider again the example we studied in section two, where we considered the industry to be engaged in large scale agriculture. A new technology may consist in passing from a method of cultivation in which each worker is responsible for all the phases of cultivation to one in which each worker is just specializing in one particular operation. Such technological upgrading would be nothing more than a better division of labor, similar to the one discussed by A. Smith. Quite obviously, all workers should be able to use both technologies and we can expect that spillover effects are not particularly significant for workers. However the new division of labor can greatly improve marginal productivity for the firm.

Condition (3.1.2) requires that exactly the opposite occurs in the case good technologies are adopted. Marginal productivity should be growing slower than the reservation utility of workers. In this case, spillover effects are so significant to induce the firm not to innovate. In the framework of the previous example, this may be the case of the adoption of technologies based on the genetic selection of seeds, which imply a great deal of human capital to be used, but it does not

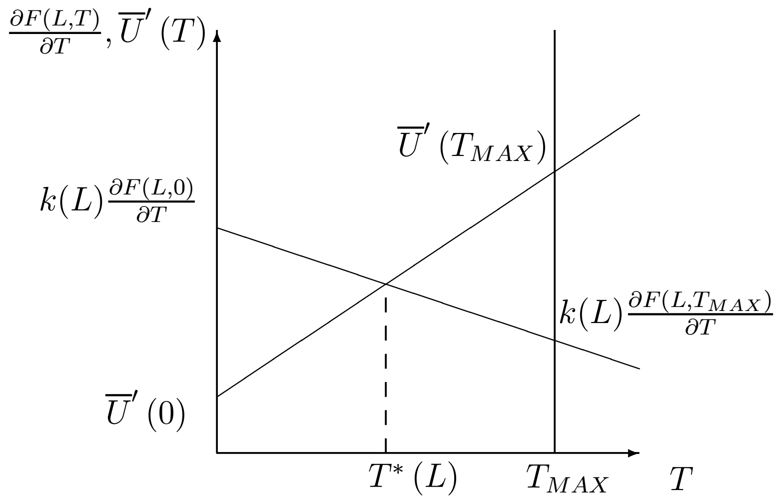

Figure 2: The adoption of an inefficient technology when $\frac{\partial^2 F(L,T)}{\partial T^2} < 0$ and $\overline{U}''(T) > 0$.

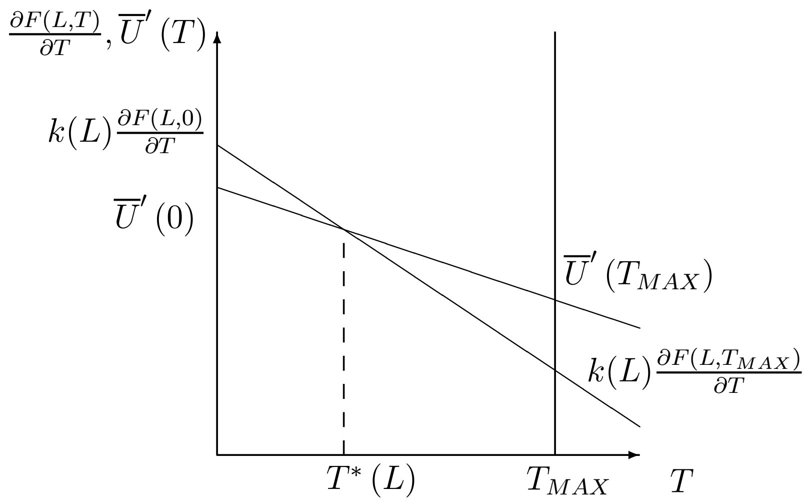

Figure 3: The adoption of an inefficient technology when $\frac{\partial^2 F(L,T)}{\partial T^2} < 0$ and $\overline{U}''(T) < 0$.

require significant investment in fixed capital. This, in turn, implies that workers may be able to apply the knowledge they acquire even in the subsistence sector, thus increasing their reservation wage. Therefore, the marginal gain for workers (associated to the adoption of an advanced technology) should be higher then the gain for the firm.

When $\frac{\partial F^2(L,T)}{\partial T^2} > 0$, given the monotonicity of $F(L,T)$ and $\overline{U}(T)$, a necessary condition for the border conditions (3.1.1) and (3.1.2) in proposition (3.1) to be satisfied is that, for any technology T, inequality (4) is satisfied. When this inequality holds, spillover effects are high enough for an inefficient technology to be adopted. In other words, the inefficiency result is driven by the importance of the spillover effects themselves.

Finally, it is straightforward to show that, without technological spillovers and taking the price for the product to be given exogenously, the firm would adopt the best technology available, T_{MAX}, for any level of L. This follows immediately from the fact that the profit function is increasing in T. That is, the firm would behave as a benevolent social planner or as a perfectly competitive firm in the labor market. Without technological spillovers, our firm would in fact be a price taker both on the product market and on the factors market. Its decision to adopt a new technology would not influence the reservation utility of workers and therefore their wages. As we already observed, the adoption of an inefficient technology derives from the market power of the firm on the labor market. The participation and incentive-compatibility constraints (i.e. $w - v(e) = (1-c)U + cw$) must still be satisfied, but there is no longer a direct correlation between utility (wage) and technology. The technology adoption problem of the firm becomes therefore

$$\underset{T}{Max}\ pF(L,T) - wL$$

and since $F(L,T)$ is increasing both in T and L, for any L, it is

$$\arg\max_{T} \{pF(L,T) - wL\} = T_{MAX}.$$

This confirms that in our framework the inefficiency result originates from the presence of spillover effects that make the reservation utility and the wage of workers endogenous with respect to the technology and, through this channel, influence the firm's decision, making innovations more costly.

4 Equilibrium employment and wage

Once, given L, the optimal technology $T^*(L)$ has been determined, we must check if, given $T^*(L)$, there exists an L maximizing the firm's objective function with respect to L. This follows immediately by the envelope theorem. In fact, since the profit function is continuous both in T and L and it is defined in a close and bounded interval, given $T^*(L)$, it must exist a value L, $L = L^*$, maximizing it. Notice that L^* might well correspond to a corner solution. However, this is completely irrelevant as far as the determination of T^* is concerned. By proposition (3.1), we know that, at L^*, there exists a technology $T^*(L^*)$ which is away from the boundary even if L^* is on the boundary, i.e. $T^*(L^*) < \overline{T} = T_{MAX}$.

We can now determine the equilibrium levels of employment and wage. Notice that the adopted technology, $T^*(L)$, determines the equilibrium level of the wage, $\widehat{w}(T^*(L^*))$, the firm must offer in order to induce workers to accept an offer and to exert the required level of effort. Moreover, the labor demand at an interior solution (i.e. $0 < L^* < N$) determines the equilibrium level of employment in the industry; i.e. the number of workers employed given the equilibrium wage. Formally, given $T^*(L)$, the firm's maximization problem is

$$\underset{L}{Max}\; pF(L, T^*(L)) - \widehat{w}(T^*(L))\,L. \tag{5}$$

The number of workers employed in equilibrium, L^*, must satisfy the first order condition

$$p\left(\frac{\partial F(L^*, T^*(L^*))}{\partial L} + \frac{\partial F(L^*, T^*(L^*))}{\partial T}\cdot\frac{\partial T^*(L^*)}{\partial L}\right) = \tag{6}$$

$$= \widehat{w}(T^*(L^*)) + \frac{\partial \widehat{w}(T^*(L^*))}{\partial T}\cdot\frac{\partial T^*(L^*)}{\partial L}L.$$

By observing that the first order condition (3) in the technology adoption problem can be written as

$$p\frac{\partial F(L, T^*(L))}{\partial T} = \frac{\partial \widehat{w}(T^*(L^*))}{\partial T}L,$$

we have:

$$p\frac{\partial F(L^*, T^*(L^*))}{\partial T}\cdot\frac{\partial T^*(L^*)}{\partial L} = \frac{\partial \widehat{w}(T^*(L^*))}{\partial T}\cdot\frac{\partial T^*(L^*)}{\partial L}L.$$

Therefore condition (6) is satisfied whenever

$$p\frac{\partial F(L^*, T^*(L^*))}{\partial L} = \widehat{w}(T^*(L^*)). \tag{7}$$

In order to determine L^*, it is therefore enough to guarantee that the equilibrium wage, given the adopted technology, is equal to the marginal productivity of labor.

By introducing explicit functional forms for $F(L,T)$ and $U(T)$ and, by solving simultaneously equations (3) and (7), it is immediate to solve for T^* and L^*. In section 5 we work out an example with explicit functional forms.

It is important to note that, as in Shapiro and Stiglitz, in our model it is impossible to reach a full employment equilibrium satisfying at the same time the participation and incentive constraints of workers. If, at T^*, it is optimal for the firm to employ all available labor force and there are no significant costs associated with being fired (loss of reputation, moving costs and so on), the threat to be fired and never re-hired is not a credible one and therefore all workers would have an incentive to shirk[17]. Only the presence of equilibrium unemployment makes the threat of firing credible. Therefore also in our model equilibrium unemployment constitutes a workers' discipline device.

At the equilibrium wage, the firm can find all the workers it needs and the workers are induced to exert the required effort. There is no reason for the firm to offer wages higher than $\widehat{w}(T^*)$ and of course there is no incentive to offer wages below $\widehat{w}(T^*)$, because they would lead to a shirking behavior by workers.

Equilibrium unemployment is involuntary. Unemployed workers would not be employed even if they are willing to accept a wage lower than $\widehat{w}(T^*)$ because, due to the imperfect monitoring mechanisms, they would not be able to credibly signal themselves as non-shirkers.

5 An example with specific functional forms

In this section, we work out an example with specific functional forms for the reservation utility function of workers and the technology used by the firm. In particular, we assume that the technology of the firm is concave both in T and L, while the reservation utility is convex in T. More precisely, the production func-

[17] This is proved in Shapiro and Stiglitz [1984]. In our model, we assume that the probability to be re-hired by the firm once fired is given exogenously and equal to 0. This assumption would be untenable at a full employment equilibrium. To illustrate Shapiro and Stiglitz's point assume that this probability is greater than 0 and denote it with a. We denote with $K \neq 0, 0 < K < L$, the number of fired workers, i.e. the flow of workers per unit of time toward the subsistence sector of the economy. The flow of unemployed toward the industry per unit of time is $a(N-L)$. At a stationary state these flows must be equal, i.e.

$$a(N-L) = K \Rightarrow a = \frac{K}{(N-L)}.$$

Whenever $L \to N$, it must be $a \to +\infty$; i.e. the probability that a fired worker is not re-hired immediately must be equal to 0.

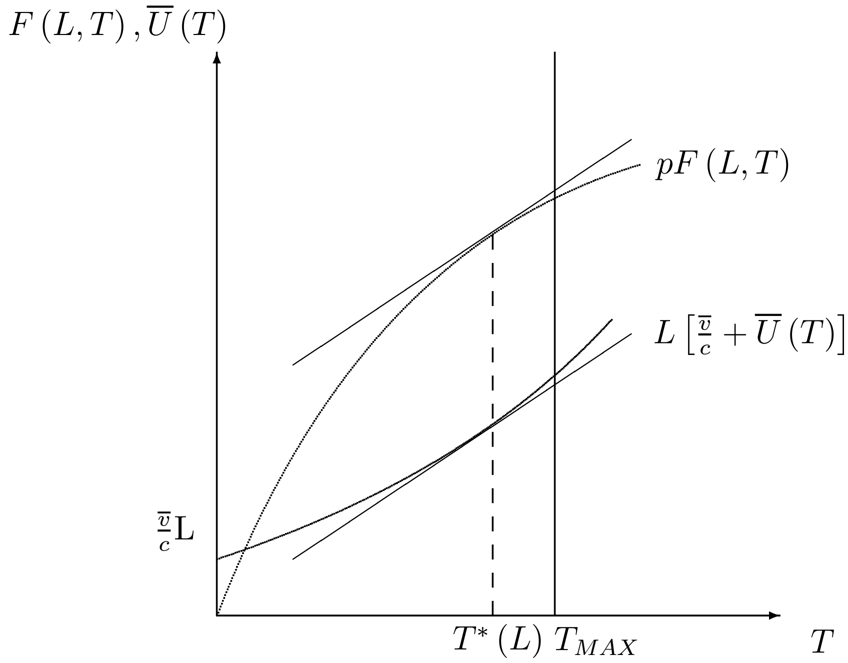

Figure 4: A graphical representation of the technology of the firm and of the reservation utility function.

tion of the firm and the reservation utility function of workers are, respectively, $F(L,T) = T^{\alpha}L^{\beta}$ and $\overline{U}(T) = T^{\gamma}$.

On these functions, we make the following assumptions.

Assumption 1: $\gamma > \alpha$, $\gamma > 1$.
Assumption 2: $\alpha < 1$.
Assumption 3: $\beta < 1$ and β such that $\beta\gamma > \alpha$.

Given L, the technology adoption problem of the firm is

$$\underset{T}{Max}\; pT^{\alpha}L^{\beta} - \left[T^{\gamma} + \frac{\overline{v}}{c}\right]L, \tag{8}$$

which is represented in Figure 4.
The first order conditions of problem (8) are

$$\alpha p T^{\alpha-1}L^{\beta} - \gamma T^{\gamma-1}L = 0$$

and, for $T \neq 0$,

$$\alpha p L^{\beta} - \gamma T^{\gamma-\alpha} L = 0$$

$$\Leftrightarrow T^{*}(L) = \left(\frac{\alpha p}{\gamma} L^{\beta-1}\right)^{\frac{1}{\gamma-\alpha}}.$$

Notice that, given the assumptions 1 and 2, the second order condition for a maximum is satisfied:

$$\underbrace{\alpha(\alpha-1)}_{<0} p T^{\alpha-2} L^{\beta} - \underbrace{\gamma(\gamma-1)}_{>0} T^{\gamma-2} L < 0.$$

Given $T^{*}(L)$, labor demand is obtained by solving the problem

$$\underset{L}{Max}\ p\left(\frac{\alpha p}{\gamma} L^{\beta-1}\right)^{\frac{\alpha}{\gamma-\alpha}} L^{\beta} - \left[\left(\frac{\alpha p}{\gamma} L^{\beta-1}\right)^{\frac{\gamma}{\gamma-\alpha}} + \frac{\overline{v}}{c}\right] L$$

i.e.

$$\underset{L}{Max}\ p\left(\frac{\alpha p}{\gamma}\right)^{\frac{\alpha}{\gamma-\alpha}} L^{\frac{\beta\gamma-\alpha}{\gamma-\alpha}} - \left(\frac{\alpha p}{\gamma}\right)^{\frac{\gamma}{\gamma-\alpha}} L^{\frac{\beta\gamma-\alpha}{\gamma-\alpha}} - \frac{\overline{v}}{c} L$$

$$\underset{L}{Max}\left[p\left(\frac{\alpha p}{\gamma}\right)^{\frac{\alpha}{\gamma-\alpha}} - \left(\frac{\alpha p}{\gamma}\right)^{\frac{\gamma}{\gamma-\alpha}}\right] L^{\frac{\beta\gamma-\alpha}{\gamma-\alpha}} - \frac{\overline{v}}{c} L, \tag{9}$$

illustrated graphically in Figure 5.

It is easy to show that the expression in square brackets in problem (9) is greater than 0 for any p.

Claim 5.1

$$p\left(\frac{\alpha p}{\gamma}\right)^{\frac{\alpha}{\gamma-\alpha}} - \left(\frac{\alpha p}{\gamma}\right)^{\frac{\gamma}{\gamma-\alpha}} > 0.$$

Proof. By taking logarithms and after some algebra

$$\underbrace{\ln p\left(1 + \frac{\alpha}{\gamma-\alpha} - \frac{\gamma}{\gamma-\alpha}\right)}_{=0} > \underbrace{\underbrace{\left(\frac{\alpha}{\gamma-\alpha} - \frac{\gamma}{\gamma-\alpha}\right)}_{\frac{\alpha-\gamma}{\gamma-\alpha}=-1} \underbrace{\ln\gamma}_{>0} + \underbrace{\left(\frac{\gamma}{\gamma-\alpha} - \frac{\alpha}{\gamma-\alpha}\right)}_{\frac{\gamma-\alpha}{\gamma-\alpha}=1} \underbrace{\ln\alpha}_{<0}}_{<0}$$

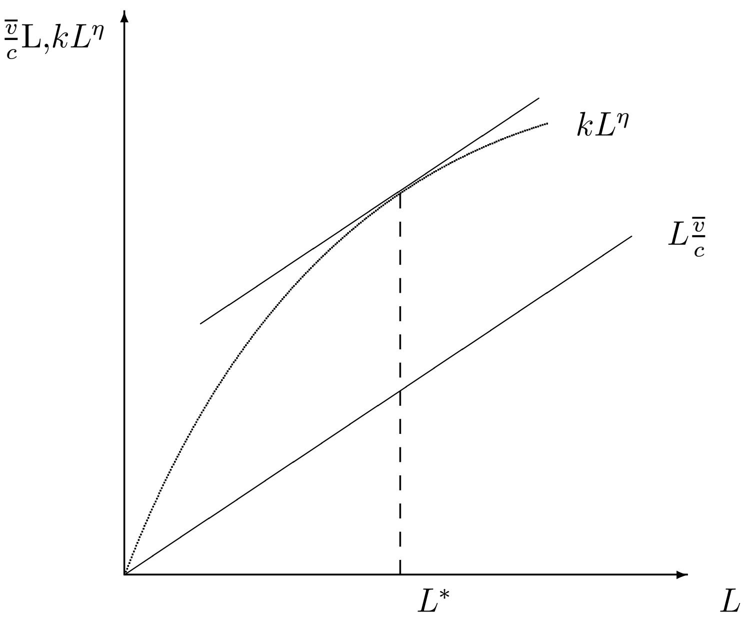

Figure 5: A graphical representation of the firm's labor demand problem, where $k = \left[p\left(\frac{\alpha p}{\gamma}\right)^{\frac{\alpha}{\gamma-\alpha}} - \left(\frac{\alpha p}{\gamma}\right)^{\frac{\gamma}{\gamma-\alpha}}\right]$ and $\eta = \left(\frac{\beta\gamma-\alpha}{\gamma-\alpha}\right)$.

which is always satisfied. ■

Let $k = \left[p \left(\frac{\alpha p}{\gamma} \right)^{\frac{\alpha}{\gamma-\alpha}} - \left(\frac{\alpha p}{\gamma} \right)^{\frac{\gamma}{\gamma-\alpha}} \right]$ and $\left(\frac{\beta\gamma-\alpha}{\gamma-\alpha} \right) = \eta$. The first order condition of problem (9) can be written as

$$k\eta L^{\eta-1} - \frac{\overline{v}}{c} = 0$$

We already know that $k > 0$. Moreover, under assumptions 1-3, it is $\eta > 0$. Therefore, we get:

$$L^* = \left(\frac{\overline{v}}{c} \frac{1}{k\eta} \right)^{\frac{1}{\eta-1}} > 0.$$

Since $\beta\gamma > \alpha$, the exponent of L, i.e. $\eta = \frac{\beta\gamma-\alpha}{\gamma-\alpha}$, is smaller than 1. This ensures that the firm's problem in L has a maximum, as it is easily seen by studying the second order condition of problem (9)

$$\underbrace{\left[p \left(\frac{\alpha p}{\gamma} \right)^{\frac{\alpha}{\gamma-\alpha}} - \left(\frac{\alpha p}{\gamma} \right)^{\frac{\gamma}{\gamma-\alpha}} \right]}_{>0} \underbrace{\frac{\beta\gamma-\alpha}{\gamma-\alpha}}_{>0} \underbrace{\frac{\gamma(\beta-1)}{\gamma-\alpha}}_{<0} \underbrace{L^{\frac{\gamma(\beta-1)}{\gamma-\alpha}-1}}_{>0} < 0.$$

Notice that, given p, α, β and γ, it is always possible to define N in such a way that an interior solution for L is obtained (i.e. $L^* < N$), which means the existence of involuntary unemployment in equilibrium.

We can now define the optimal technology adopted by the firm. Since

$$T^*(L) = \left(\frac{\alpha p}{\gamma} L^{\beta-1} \right)^{\frac{1}{\gamma-\alpha}},$$

it is immediate to obtain

$$T^*(L^*) = \left(\frac{\alpha p}{\gamma} \left(\frac{\overline{v}}{c} \frac{1}{k\eta} \right)^{\frac{\beta-1}{\eta-1}} \right)^{\frac{1}{\gamma-\alpha}} = \left(\frac{\alpha p}{\gamma} \right)^{\frac{1}{\gamma-\alpha}} \left(\frac{\overline{v}}{c} \frac{1}{k\eta} \right)^{\frac{1}{\gamma}}.$$

Proposition 3.1 in Section 3 can now be restated as

If, for all $L \in [0, N]$*, the assumptions on* $F(L,T)$ *and* $\overline{U}(T)$ *[i.e.* $F(L,T) \in C^2$, $\frac{\partial F(L,T)}{\partial T} > 0$, $\frac{\partial^2 F(L,T)}{\partial L^2} < 0$ *and* $\overline{U}(T) \in C^2$, $\overline{U}'(T) > 0$, $\overline{U}''(T) > 0$*], and the following boundary conditions hold:*

1.1 $p\frac{\partial F(L,T)}{\partial T} \mid_{T=0} > L\overline{U}'(T) \mid_{T=0}$;

1.2 $p\frac{\partial F(L,T)}{\partial T} \mid_{T=T_{MAX}} < L\overline{U}'(T) \mid_{T=T_{MAX}}$

then, $\forall\ L \in [0, N]$*, the problem*

$$\begin{cases} \underset{T}{Max}\ pF(L,T) - wL \\ s.t.\ w - \overline{v} = c\overline{U}(T) + (1-c)w \end{cases}$$

has a unique interior solution $T^*(L), T^*(L) \in (0, T_{MAX})$*.*

Proof. The only thing that we need to check is if the boundary conditions 1.1 and 1.2 are satisfied for the above example.

1. $p\frac{\partial F(L,T)}{\partial T} \mid_{T=0} > L\overline{U}'(T) \mid_{T=0}$:

$$\underbrace{\alpha T^{\alpha-1}L^{\beta} \mid_{T=0}}_{\to+\infty} > \underbrace{\gamma T^{\gamma-1} \mid_{T=0}}_{=0},$$

2. $p\frac{\partial F(L,T)}{\partial T} \mid_{T=T_{MAX}} < L\overline{U}'(T) \mid_{T=T_{MAX}}$.

It is enough to define a T_{MAX} such that $T_{MAX} > T^*(L^*)$. This is always possible as $T^*(L^*)$ is a finite number for any choice of the parameter values. ■

6 Concluding remarks and extensions

In this paper we investigate the technology adoption problem faced by a firm price maker on the labor market and price taker on the good market. The main feature of our model is the relationship between the reservation utility of workers and the technology adopted by the firm. On the one side, the adoption of a superior technology increases the productivity of employed workers and the profits of the firm. On the other side, it implies an increase in the cost of labor induced by the presence of spillovers related to the fact that workers learn (for convenience instantaneously) the new technology, which implies an increase in their reservation utility, provided they can exploit their knowledge elsewhere. This in turn induces an increase of the wage the firm must offer in order to induce workers to accept its employment offer and to exert the required level of effort (as in the standard efficiency wage model). That is, the participation constraint of workers becomes endogenous in the technology choice.

The adoption of a new technology can determine an increase in the wage sufficient to induce a profit-maximizing firm not to adopt the superior technology, in order to avoid the impact of induced spillovers on the cost of labor. The direct implication of this reasoning is an inefficiency result in the technology adoption problem. However, the channel through which this result is obtained differs substantially from the standard one in the literature, focusing on the role of adoption and adjustment costs to explain the adoption of inferior technologies.

The model we present in this paper is a first attempt to model the role of spillover effects. The economy we consider is a very simple one and our framework can be extended in many ways. In particular, it may be useful to extend it taking explicitly into account the skills of workers and the disutility associated to their acquisition, as well as endogenizing the disutility of effort with respect to the technology adopted by the firm. We have already conjectured that the adoption of a better technology might have an impact on the disutility of effort, reducing it. This, in turn, reduces the incentives for a worker to shirk.

On a more technical ground, the simplifying assumptions on the probability to be fired and to be re-hired can be generalized. By assuming the probability to be re-hired being equal to zero, we rule out some features that can be included in the model. If N is not big enough, it may be possible that the number of workers fired, because of shirking, is bigger than the number of workers never employed by the firm. In this case, the firm may be forced to hire workers it fired in the past and this, of course, reduces the punishment associated with being fired. Moreover, as already observed, the assumption of an ever-lasting unemployment phase becomes contradictory should the economy be close to a full employment equilibrium. On the other hand, the labor-saving nature of technological progress reduces the likelihood of being rehired once fired, thus reducing the wages the firm must pay in order not to induce shirking behaviors. This effect would be reinforced by taking into account the heterogeneity of workers while evaluating the probability of being re-hired. In fact, once fired, a shirker suffers a loss of reputation, which makes more difficult for him (her) to be hired again.

Many assumptions in our model are justified by the emphasis on the role of spillover effects. In particular, the assumption of risk neutrality of workers, the absence of a capital sector and the presence of only one industry and firm are going in this direction. Quite intuitively, the introduction of risk averse workers, the presence of an imperfect capital market or a low degree of complementarity between firms in different industries would all reduce the probability that a worker can transform easily in an entrepreneur using the knowledge he acquires while working for a firm. The presence of such factors would make more difficult to take advantage of the spillover effects associated to the adoption of a better technology and therefore would reduce the costs of innovation for the firm.

The framework proposed in this model seems to be potentially useful to investigate problems of economic growth and development. A dynamic extension of the model in an intertemporal setting can be used to explain the absence of superior technology adoption and the slow pace of economic growth in poor countries for which the empirical evidence suggests a significant degree of monopolistic power. Before being able to tackle these questions, however, it is important to remove the restrictive assumption of only one firm operating in the production sector of the economy, which is almost never supported by the empirical evidence. Qualitatively, the arguments and the results of this paper should go through even when strategic interactions between industries and between firms in a specific industry are introduced. The important point is the presence of market power on the labor market and not the degree of competition in the final good market. The presence of many firms competing on the labor market would however complicate the analysis of the interaction between firms and workers[18]. It seems reasonable to believe that the costs associated to the choice of a superior technology becomes bigger, because the presence of many firms increases the size of the space of outside options available to workers and it induces a strategic use of the adoption timing by different firms. A careful investigation of the effects of strategic interaction between firms is an important point of the agenda for future research.

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