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Abstract

An optimizing representative firm pays efficiency wages to skilled workers to produce technological innovations, which are assumed to be of labor saving type, affecting negatively the hiring rate of unskilled workers. The results are: i) The efficiency wage of skilled workers is determined by the Solow condition; ii) There is underemployment of unskilled workers whenever the added value of innovations is greater than the opportunity cost of skilled workers' wages; iii) The optimal level of technology is independent of technological parameters; iv) The employment of skilled workers increases with the level of technology and decreases with the efficiency wage; v) The employment of unskilled workers is not necessarily negatively affected by technological innovations in the steady state.

JEL Classification Numbers: D29, D92, J41, O33

Key Words: Unemployment; Efficiency wage models; Technological change

1.Introduction

Recent literature has emphasized the important role of R&D and technological innovation as engine of the so-called endogenous growth (e.g Barro and Sala-i-Martin, 1995). On the main focuses of attention has been on the impact of human capital in the production of new goods, production processes and technology (e.g Romer,1990).The optimal allocation of human capital in the production of technology brings forward the design of incentives for skilled workers. This issue has been tackled by research based on agency theory and related models (e.g Aghion and Tirole,1994). Efficiency wage models provide a simple form of incentive; which postulates a positive relationship between workers'effort and dedication and the wage paid by firms. In its static formulation, the efficiency wage is set by an optimizing firm at the level that the effort-wage elasticity is equal to unity, which is known as the Solow condition (Solow,1979).

This paper presents an inter-temporal model where profit maximizing firms pay efficiency wages to skilled workers (scientists and engineers) as an incentive for them to create new modern knowledge that can be used in the industrial production process. The firms produce one final good employing unskilled workers and use the technology created by skilled workers. Unskilled workers are assumed to receive the market –clearing wage. The number of unskilled workers varies according to technological innovations. That is, jobs will be destroyed if technological innovations are labor saving type, which implies that the less unskilled will be hired after the technology has been adopted.

A number of appealing results are derived from our model. First, the efficiency wage paid to skilled workers is given by the Solow condition; Akerlof and Yellen (1986) argues due to the presence of turnover and/or shirking costs, firms have to pay a higher wage than one given by the Solow condition. The Solow condition also came under attack in recent dynamic efficiency wages (e.g Lin and Lai, 1994, Faria ,2000); Specifically, in dynamic models on knowledge creation and efficiency wage as Jellal and Zenou (2000), it is shown that the Solow condition does not hold necessarily. Therefore, our result is in sharp contrast with this literature.

The model also shows that the steady state modern industrialization given by the reached technological levels balances the hiring rate of unskilled with the quit rate. As a consequence, technology is not affected by the parameters of the production functions. Moreover, the employment strategy of skilled workers increases with technology and decreases with the efficiency wages. Finally, despite the introduction of labor saving technological innovation, the equilibrium number of unskilled workers is not necessarily negatively affected by technological path in the steady state.

The paper is organized as follows. The next section presents the basic model. The analysis of the steady state equilibrium appears in the section three. Section four concludes.

2. The Model

The representative firm employs two types of workers: skilled and unskilled. Skilled labor (S) is used to produce modern technical knowledge (A); In order to stimulate skilled workers the firm pays a wage above the market-clearing for skilled workers, that is, the firm pays efficiency wage w to skilled workers and market-clearing wage w_o to unskilled workers. The stock of knowledge of the firm varies according to the difference between new knowledge of technology created by skilled workers and the knowledge that depreciates with time:

$$\dot{A} = G(e(w)S) - \delta A \quad (1)$$

Where $\delta > 0$ is the depreciation (obsolescence) rate of the stock of knowledge and $G(\cdot)$ is a well behaved production function of knowledge:

$$G'(\cdot) > 0, G''(\cdot) < 0$$

The production function of the modern knowledge increases with number of skilled workers and their effort. The effort function $e(w)$ increase with the efficiency wage : $e'(w) > 0, e''(w) < 0$ ¹.

In order to model job creation, it is assumed that the number of employed unskilled workers (N) vary along time according to the difference between the number of hired unskilled workers (hN) and the number of unskilled workers that decide to quit from the firm (QN) (e.g, Hoon and Phleps,1992). In line with the Ricardian idea that technological innovations displace workers (see Ricardo,1821), the hiring rate (h) of unskilled workers is supposed to decrease with technological innovations² :

$$h(A), h'(A) < 0, h''(A) > 0$$

$$\dot{N} = (h(A) - Q)N \quad (2)$$

Finally, it is assumed that the firm internalizes all knowledge that is being produced by its skilled workers such as to use it as technology to produce the final good (Y) which price is normalized to unity. The production function of the final good depends on the stock of knowledge and the number of unskilled workers:

$$Y = F(A, N), F_A, F_N > 0, F_{AA}, F_{NN} < 0, F_{AN} > 0 \quad (3)$$

The firm is assumed to maximize the present value of its cash flow by choosing the efficiency wage path and the number of skilled labor. Hence, the firm has to solve the following dynamic program:

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¹ In Shell's (1966) seminal paper, technical knowledge is produced using a fraction of the output of the firm. In the present model the firm finances its R&D by paying skilled workers, and this is reflected on the cash flow of the firm.

² The idea that great part of technological innovation is biased toward labor saving technologies appears in Hicks (1932) , and triggered an enormous literature[e.g., Fellner (1961), Kennedy(1964), and Samuelson (1965), see Acemoglu (2001) for a modern approach].

$$\text{Max}_{w,S} \int_{R^+} [F(A,N) - wS - w_o N] e^{-rt} .dt \quad (4)$$

subject to:

$$\dot{A} = G(e(w)S) - \delta A$$

$$\dot{N} = (h(A) - Q)N$$

$$A(0), S(0), N(0) > 0 .$$

To solve this problem consider the following Hamiltonian function:

$$H = F(A,N) - wS - w_o N + \lambda [G(e(w)S) - \delta A] + \mu [h(A) - Q]N$$

where λ and μ are the costate variables of A and N , respectively, and represent the shadow prices of A and N as well.

The first order conditions are given by:

$$H_S = 0 \Rightarrow \lambda G'(e(w)S) e(w) = w \quad (5)$$

$$H_w = 0 \Rightarrow \lambda G'(e(w)S) e'(w) = 1 \quad (6)$$

$$\dot{\lambda} - r\lambda = -H_A = -[F_A(A,N) - \lambda\delta + \mu h'(A)N] \quad (7)$$

$$\dot{\mu} - r\mu = -H_N = -[F_N(A,N) - w_o + \mu(h(A) - Q)] \quad (8)$$

plus equations (1) and (2) and the transversality conditions.

The first result of this paper comes from the analysis of the above system. From equations (5) and (6) we obtain the following proposition.

Proposition 1

“The efficiency wage is given by the Solow condition:

$$\frac{e'(w)w}{e(w)} = 1 \quad .”$$

Proof:

The result is obtained directly from the equation (5) and (6).

The equilibrium condition : $\frac{e'(w)w}{e(w)} = 1$ (9) determines the equilibrium

value of the efficiency wage paid by the firm to skilled workers. It is important to stress that this condition is precisely the Solow condition. That is, in this dynamic efficiency wage model the optimal efficiency wage paid to skilled workers is given by the static Solow condition.

3. The Steady State Equilibrium

In the past section, the equilibrium value of the efficiency wage paid to skilled workers was determined by the usual Solow condition. In order to determine the equilibrium values of the remaining endogenous variables of the model, we assess the stationary solution, which is found when :

$$\dot{\lambda} = \dot{\mu} = \dot{A} = \dot{N} = 0$$

$$h(A) = Q \quad (10)$$

$$G(e(w)S) = \delta A \quad (11)$$

$$\lambda = \frac{1}{G'(e(w)S)e'(w)} \quad (12)$$

$$(r + \delta)\lambda = F_A(A, N) + \left[\frac{F_N(A, N) - w_o}{r} \right] \cdot h'(A)N \quad (13)$$

$$\mu = \frac{F_N(A, N) - w_o}{r} \quad (14)$$

The system of equations (10)-(14) determines the equilibrium values of the level of the modern technology A^* , the number of skilled workers S^* , the shadow price of knowledge creation λ^* , the number of unskilled workers N^* , and the shadow price of job creation μ^* . It is easy to observe that this is a block recursive system. Equation (10) determines the equilibrium of level of technology that balances the hiring rate with the quit rate of the unskilled workers. Given A^* and, w^* , the optimal number of skilled workers is found through equation (11), which balances the creation of new technical knowledge with the depreciation of old knowledge. Given S^* and, w^* , from equation (12) the shadow value of knowledge

creation is determined. With λ^* , and A^* , the equilibrium number of unskilled is given by equation (13).

Finally, given N^* and, A^* , the shadow value of job creation μ^* is determined.

It is important to note that in the above solution, due to positive technological spillovers, the marginal productivity of the unskilled workers can be greater than their wage. Notice that if the unskilled workers are paid their marginal productivity :

$$F_N(A, N) = w_o \quad (15)$$

It follows from equation (14) that the equilibrium shadow price of job creation is zero: $\mu^* = 0$, and, equation (13) vanishes to :

$$(r + \delta)\lambda = F_A(A, N) \quad (13')$$

as a consequence the system becomes super-determined and equation (13') becomes redundant to determine the number of unskilled workers employed by the firm, which is now given by equation (15).

A close inspection of equation (13) shows that we can write the sign of $(F_N(A, N) - w_o)$ as (recalling that $h'(A) < 0$) :

$$\text{Sgn}(F_N(A, N) - w_o) = \text{Sgn}\left(F_A(A, N) - \frac{(r + \delta)}{G'(e(w)S)e'(w)}\right)$$

Using equations (9) and (11), we have:

$$\text{Sgn}(F_N(A, N) - w_o) = \text{Sgn}\left(F_A(A, N) - \frac{(r + \delta)Sw}{e(w)SG'(e(w)S)}\right)$$

Let $M = e(w)S$, $g = \frac{MG'(M)}{G(M)}$, $\eta = \frac{AF_A(A, N)}{F(A, N)}$, $\theta = \frac{wS}{F(A, N)}$, and we obtain the

following result.

Proposition 2

“The unskilled workers size of employment is given by the following condition:

$$Sgn(F_N(A, N) - w_o) = Sgn(\delta\eta g - (r + \delta)\theta) \quad .”$$

Proof:

The condition is obtained by simple substitution of parameters.

On can immediately observe that we have the following insight given by :

$$\begin{aligned} \text{Under-employment when : } Sgn(F_N(A, N) - w_o) = Sgn(\delta\eta g - (r + \delta)\theta) > 0 \Rightarrow \\ (\delta\eta g - (r + \delta)\theta) > 0 \Rightarrow \delta\eta g > (r + \delta)\theta \end{aligned}$$

where $\delta\eta g$ is the added value of new innovation, while $(r + \delta)\theta$ is the associated opportunity cost in terms of the skilled workers wages. The under-employment of unskilled workers is due to the firm's skill bias. The firm prefers to hire skilled workers whenever the added value of innovations is greater than the opportunity cost of skilled workers' wages. This lead to an under-employment of less skilled workers (unskilled). Of course the situation is inverted and we have over-employment of unskilled workers whenever the following condition holds :

$$\delta\eta g < (r + \delta)\theta$$

Corollary 1

“The comparative static analysis of the steady state equilibrium raises the following results:

- i) The equilibrium level of modern technology is independent of the efficiency wage as well as from the parameters of the production function of knowledge and final good
- ii) The equilibrium size of skilled workers increases with the level of technology and decreases with the efficiency wage.
- iii) The equilibrium shadow value of knowledge creation decreases with the efficiency wage and increases with the size of skilled workers.
- iv) The impact of the modern reached technology on the employment of unskilled workers is ambiguous. A rise in A^* can lead to more or less unemployment of unskilled workers. This is an interesting result, since we are using the Ricardian assumption that the technology is labor saving, one would expect to see a negative relationship between technology adoption and the unskilled labor employment in the steady state. .”

4. Conclusion

This paper presents a model in which the firm aiming to upgrade her industry employs skilled workers to produce modern advanced technological knowledge. The firm employs this knowledge with unskilled workers to produce a final good. It pays efficiency wages as device to provide incentives for skilled workers. Technological innovations are assumed to be labor saving type, affecting negatively the hiring of unskilled workers.

The solution of the model provides many appealing results relating efficiency wages, technological innovations and employment. The efficiency wage of skilled workers is determined by the Solow condition. There is under-employment of unskilled workers whenever the added value of innovations is greater than the opportunity cost of skilled workers' wages. The optimal level of modern technology is independent of technological parameters. The employment of skilled workers increases with the level of technology and decreases with the efficiency wage. The employment of unskilled workers is ambiguously affected by technology.

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