

## Technological change, relative wages, and unemployment

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### Abstract

This paper examines the effect of skilled-biased technological shocks on the structure of wages and the composition of employment in a two-sector economy with a heterogeneous work force. Efficiency wage considerations, turnover costs and minimum wage legislation lead to labor market segmentation and equilibrium unemployment. The analysis focuses on the effects of a technological shock that raises the demand for skilled labor and reduces the demand for unskilled labor, in such a way that the total demand for labor in the primary (high wage) sector remains constant at initial wages. The presence of efficiency considerations implies that such a shock tends to reduce total employment in that sector, as the equilibrium increase in skilled labor employment is smaller than the drop in the employment of unskilled labor. Efficiency factors and initial unemployment are shown to magnify the adverse employment effects of pro-skilled technological progress.

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## **1. Introduction**

Well-documented features of the labor market in several industrial countries in the 1980s have been a fall in the relative wage of unskilled workers, and a relative increase in employment of highly-educated workers. Lawrence and Slaughter (1993) found, for instance, that in the United States the ratio of average payroll wages of non-production workers relative to those of production workers rose by nearly 10 percent between 1979 and 1989 in the manufacturing sector. During the same period, as documented by Katz and Murphy (1992), the ratio of non-production to production workers in manufacturing rose by almost 25 percent. Along the same lines, Bound and Johnson (1992) found that between 1979 and 1988 the ratio of the average wage of college graduates increased by over 15 percentage points relative to the average wage of high school graduates. Similar trends have been identified for Canada (Prasad, 1994), Italy (Demekas, 1994), the United Kingdom (Machin, 1994), Japan and – mostly since the mid-1980s – France (Katz et al., 1994). Machin (1994), for instance, estimated that the share of non-manual employment in total employment in the manufacturing sector in the United Kingdom rose from 16.1 percent in 1948 to 32.7 percent by 1990, while the share of non-manual wage costs rose from 23.1 percent to 42 percent. During the 1980s, the share of non-manual workers in total employment rose by about 0.4 percentage point per annum, while the gap between highest- and lowest-paid workers widened substantially, with a sharp rise in the relative pay of non-manual workers.

Several explanations have been offered to account for these dramatic changes in the wage structure and the composition of employment. Some authors have argued that in the United States the large increase in the supply of unskilled labor through legal and illegal immigration has had a significant effect on relative wages, although the evidence at the national level appears inconclusive. Others, such as Katz et al. (1994), have argued that the deceleration in the rate of growth of the relative supply of highly-educated workers has had a large effect on wage differentials, in both the United Kingdom and the United States. Several economists in Europe and the United States – for instance, Borjas and Ramey (1994) – have emphasized the role of changes in the composition of external trade, particularly the effect of competition from low-cost foreign producers, which has induced a shift in manufacturing activities away from labor-intensive, low value-added industries. Finally, some observers have argued that the decline in the relative price of capital (resulting from a steeper fall in the user cost of capital relative to the reduction in real wages) observed in some industrial countries has led to increased substitution between capital and unskilled labor, thus reducing demand for that category of labor. At the same time, because skilled labor and capital tend to be complements, it has raised demand for skilled workers. In Canada, it appears indeed that the change in the composition of labor demand has been particularly marked in industries where unskilled labor and capital tend to be substitutes, and skilled labor and capital complements (Prasad, 1994).

A view shared by a number of economists is that both the change in the relative wage structure and the composition of employment were caused by a large shift in relative labor demand away from workers with limited qualifications and towards those with higher skill levels. In addition, several authors – including Berman et al. (1994), Bound and Johnson (1992), Brauer and Hickok (1995), Krueger (1993), and Mincer (1991) in the United States, and Machin (1994) in the United Kingdom – have argued that this relative demand shift appears to have resulted primarily from technological progress biased towards skilled labor and not from ‘supply’ factors, such as increases in the participation rate of unskilled workers, or a deceleration in the rate of growth of the relative supply of college-educated workers. In particular, Berman et al. (1994), Krueger (1993), and Machin (1994) have presented direct evidence on the relationship between skill-biased technological change and changes in the wage structure. The debate, however, is not settled yet. It has been emphasized, in particular, that some of the proposed explanations are not necessarily exclusive of each other. The adoption of skill-biased technological change, for instance, may result from an attempt by firms to improve their competitive position (relative to newly-industrialized countries, for instance) by shifting to high value added production processes, thereby reducing the relative demand for unskilled workers and raising the relative pay of skilled workers.

Our contribution to the ongoing debate is to propose in this paper a formal analytical framework that allows examining the effect of technological shocks of the type alluded to above on the structure of wages and the composition of employment. The model that we develop has a number of appealing features in that regard. It relates to an economy in which the existence of efficiency considerations, turnover costs, and minimum wage legislation lead to labor market segmentation and possibly to the emergence of equilibrium unemployment. Specifically, our analysis extends the seminal shirking model of Shapiro and Stiglitz (1984) to a two-sector economy where the labor force is heterogeneous. Efficiency wages are paid only to skilled workers, while unskilled workers in the ‘primary’ sector earn a legally-binding minimum wage. Wages in the ‘secondary’ sector are determined on the basis of turnover costs.<sup>1</sup>

The remainder of the paper is organized as follows. Section 2 describes the analytical framework. Section 3 examines the implications of a large technological shift that economizes on the use of unskilled labor and raises the use of skilled labor in the primary sector. It discusses, in particular, the effect of the shock on

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<sup>1</sup> Models of segmented labor markets in which efficiency wages are determined along the lines suggested by Shapiro and Stiglitz (1984) have been developed by Bulow and Summers (1986) and Jones (1987). In particular, Jones shows that a large enough differential between the primary- and secondary-sector wages removes the need for (unvoluntary) unemployment as a “discipline device”, as emphasized by Shapiro and Stiglitz (1984). However, these studies consider only the case of a homogeneous work force.

relative wages and unemployment of both categories of workers. Section 4 summarizes the main results of the analysis.

## 2. Analytical framework

The economy considered here employs two categories of workers and possesses two production sectors, which are distinguished by two sets of characteristics: differences in wage formation, and the production technology. Firms are in fixed numbers in each production sector. In the primary sector, production requires highly-qualified workers as well as unskilled workers. Labor legislation is binding and wages are set by government fiat (for unskilled labor) or firms' optimizing decisions (for skilled labor).<sup>2</sup> In the secondary sector, the production process requires only workers with limited qualifications. Firms face significant turnover costs and determine both wages and employment to maximize profits. There are no physical or institutional impediments to mobility across sectors, for either category of workers. Skilled workers may thus seek employment as unskilled workers in the secondary sector.

### 2.1. Workers' decisions

The total labor force is fixed and equal to  $\bar{L}$ . The number of skilled or 'educated' workers is equal to  $\bar{L}_E$ , and the number of unskilled workers is  $\bar{L}_U \equiv \bar{L} - \bar{L}_E$ . Skilled workers are risk-neutral and dislike effort. Their instantaneous utility function takes the linear form  $u(\omega, e) = \omega - e$ , where  $\omega$  is the wage earned in the sector of employment and  $e$  the level of effort demanded by employers. As in Shapiro and Stiglitz (1984), effort when employed in the primary sector is a discrete variable: high-ability workers either supply the constant positive level of effort required from them ( $e = e > 0$ ) or no effort at all ( $e = 0$ ). When employed in the secondary sector, however, skilled workers always provide the level of effort  $e = e_U$ , where  $0 \leq e_U < e$  represents the constant level of effort provided by unskilled workers, regardless of the sector of occupation. Unskilled workers are also risk neutral, so that their instantaneous utility function (appropriately normalized) can be written as  $u(\omega, e_U) = \omega - e_U$ . The minimum wage is assumed higher than the secondary sector wage, so that unskilled workers look for job opportunities in the primary sector first.<sup>3</sup> Both categories of workers have

<sup>2</sup> More generally, it could be assumed that the government sets a minimum wage for both categories of labor in the primary sector, but that the legislated wage is binding only for unskilled workers.

<sup>3</sup> It could be assumed that employment in the primary sector provides an additional, nonpecuniary benefit – such as an enhanced social status – which would create additional incentives for unskilled workers to look for employment there first. This treatment would imply that (in equilibrium) the secondary sector wage can be either higher or lower than the legal minimum wage.

infinite lives, and discount future earnings at the constant rate  $\rho > 0$ . Neither group may lend or borrow.

## 2.2. Wages and employment

Firms in the primary sector use both skilled and unskilled labor to produce a quantity  $Q_P$  of a traded good whose price is normalized to unity. The production function is approximated by a quadratic form, as for instance in Akerlof and Yellen (1990):

$$Q_P(L_E, L_{PU}) = a_1 L_E + a_1 L_{PU} - a_{11} L_E^2/2 - a_{22} L_{PU}^2/2 + \sigma L_E L_{PU}, \quad (1)$$

where  $L_E$  and  $L_{PU}$  denote skilled and unskilled employment in the primary sector, and  $a_1$ ,  $a_2$ ,  $a_{11}$ , and  $a_{22}$  are positive coefficients. Specification (1), being a second-order approximation, is consistent with a large variety of underlying production technologies. The coefficient  $\sigma$  can be positive, in which case skilled and unskilled labor are (gross) complements in the production of the primary sector good, or negative, in which case skilled and unskilled labor are (gross) substitutes. The existing evidence for industrial countries suggests that production and non-production workers are Hicks–Allen substitutes, that is, that the output-constant cross elasticities of demand for each category of labor are positive (see Hamermesh, 1993). This, however, does not preclude the possibility that these two groups of workers may be gross complements, or that the output effect dominate the substitution effect.<sup>4</sup> In what follows, we will assume that  $\sigma > 0$  – an assumption which is tantamount to viewing skilled workers as ‘managers’ and unskilled workers as ‘blue collars’. As will be made clear below, while this condition is sufficient to establish the main results of the paper, it is not necessary. The main requirement is that the concavity terms in the production function be large enough in relation to  $\sigma$ , so that  $a_{11} + \sigma > 0$  and  $a_{22} + \sigma > 0$ . These conditions hold trivially if the two labor categories are gross complements.

Unskilled workers employed in the primary sector provide, as indicated earlier, a constant level of effort  $e_U < e_E$ . However, firms in the primary sector cannot monitor perfectly on-the-job effort by high-ability workers. The monitoring technology is assumed to be such that there exists a constant probability  $\pi$  that a skilled worker engaged in shirking is caught.<sup>5</sup> If caught, the worker is fired and faces two options. He either remains unemployed in the primary sector and receives an unemployment benefit, or he seeks employment as unskilled labor in

<sup>4</sup> In addition, it can be shown that if the production function exhibits constant returns to scale and if the only inputs are the two labor types, then the two inputs are complements. For a constant returns-to-scale production function with more than two inputs, the ‘average’ pairs of inputs are also complements (see for instance Becker, 1971, p. 117).

<sup>5</sup> For an efficiency-wage model in which the monitoring technology is endogenous, see Chatterji and Sparks (1991).

the secondary sector.<sup>6</sup> The choice is assumed to depend solely on whether the unemployment benefit is higher or lower than the going wage in the secondary sector, adjusted for the disutility of effort.<sup>7</sup> Workers in the secondary sector can engage in on-the-job search, so that the probability of finding a job in the primary sector for a skilled worker who is initially unsuccessful is independent of whether he remains unemployed or works in the secondary sector.<sup>8</sup> Firms in the primary sector set skilled workers' wage so as to deter them from shirking and induce them to provide the required level of effort.

Let  $b_E$  denote the exogenous turnover rate per unit time for skilled workers. Following Shapiro and Stiglitz (1984), we use the 'asset equations' to derive the wage of skilled workers. Let  $V_{P_s}^E$  denote the expected lifetime utility of a high-ability worker currently employed in the primary sector who chooses to shirk, and let  $V_{P_n}^E$  be the expected utility stream if the employed worker is not shirking. The asset equations are given by

$$\rho V_{P_s}^E = \omega_E + (b_E + \pi)(V_N^E - V_{P_s}^E), \quad (2a)$$

$$\rho V_{P_n}^E = \omega_E - e_E + b_E(V_N^E - V_{P_s}^E), \quad (2b)$$

where  $\omega_E$  is the equilibrium wage for skilled workers and  $V_N^E$  the expected lifetime utility of a high-ability worker who is not employed in the primary sector. Eqs. (2a) and (2b) indicate that the interest rate times the asset value equals the flow benefits (dividends) plus the expected capital gain (or loss). For instance, if a skilled worker shirks, he obtains the wage  $\omega_E$  without providing any effort but faces a probability equal to  $b_E + \pi$  of losing his job, thus incurring a loss in welfare equal to  $V_{P_s}^E - V_N^E$ .

To elicit positive effort requires that  $V_{P_n}^R \geq V_{P_s}^E$ , so that

$$\omega_E \geq \rho V_N^E + e_E \Lambda / \pi, \quad \Lambda \equiv \rho + b_E + \pi. \quad (3)$$

Eq. (3) is the no-shirking condition (NSC) derived by Shapiro and Stiglitz (1984). In equilibrium this condition holds as an equality, and a rational worker will be indifferent between working and not working – in which case we assume he chooses to work.

<sup>6</sup> A third possibility would be for a skilled worker to seek employment as unskilled labor in the primary sector. We exclude this case by assuming that an employer whose aim is to minimize frictions among co-workers would refrain from hiring skilled workers to work as unskilled labor, along with highly-qualified workers in skilled positions. This tendency is reflected in the observed practice of not employing overqualified workers.

<sup>7</sup> Other factors that may matter in the choice between unemployment and secondary sector employment are both economic – for instance, whether secondary employment has an adverse signaling effect – and non-economic, such as the perceived loss of social prestige. Note also that because employment in the secondary sector is demand constrained (as explained below), the decision to look for a job in the secondary sector is no guarantee of actually finding one.

<sup>8</sup> Pissarides and Wadsworth (1994) recently found that skilled workers have a preference for searching while employed – although search intensity appears to vary with job tenure.

The wage for unskilled labor in the primary sector is set by the government at the minimum level  $\omega_U^*$ . Using Eq. (1), under profit maximization the demand functions for skilled and unskilled labor can be shown to be

$$L_{PU}^d(\omega^*, \omega_E; \sigma) = [(a_2 - \omega_U^*)a_{11} + \sigma(a_1 - \omega_E)]/\Delta, \tag{4a}$$

$$L_E^d(\omega^*, \omega_E; \sigma) = [a_{22}(a_1 - \omega_E) + \sigma(a_2 - \omega_U^*)]/\Delta, \tag{4b}$$

where  $\Delta \equiv a_{22}a_{11} - \sigma^2 > 0$ , from the second-order conditions for profit maximization. Eqs. (4a) and (4b) show that the effect of an increase in the minimum wage on the demand for skilled labor as well as the effect of an increase in the efficiency wage on the demand for unskilled labor depend on whether labor inputs are complementary or not. Since  $\sigma$  is assumed positive here,  $\partial L_{PU}^d/\partial \omega_E < 0$  and  $\partial L_E^d/\partial \omega_U^* < 0$ .

Firms in the secondary sector produce a quantity  $Q_S$  of a traded good whose domestic price is also set at unity, using unskilled labor in quantity  $L_S$ . Supervision and monitoring are costless, so that employed workers (as indicated above) always provide the required level of effort  $e_U$ . The production technology is characterized by diminishing returns to labor and also takes a quadratic form for tractability:<sup>9</sup>

$$Q_S(L_S) = h_0 + h_1L_S - h_{11}L_S^2/2, \quad h_1, h_{11} > 0. \tag{5}$$

Firms in the secondary sector face two types of labor costs: normal costs associated with the use of labor in production, and a cost of  $\delta qL_S$  incurred in hiring and training new workers, where  $\delta > 0$  is the cost incurred per worker and  $q$  the quit rate. Profits of a representative firm in the secondary sector are thus given by

$$Q_S(L_S) - (\omega_U + \delta q)L_S, \tag{6}$$

where  $\omega_U$  denotes the secondary-sector wage. The quit rate in the secondary sector is the outcome of labor turnover in the primary sector:

$$q = (b_E L_E^d + b_U L_{PU}^d)/(\bar{L} - L_E^d - L_{PU}^d), \tag{7}$$

where  $b_U$  is the turnover rate for unskilled workers in the primary sector, and  $\bar{L} - L_E^d - L_{PU}^d$  measures the total potential supply of labor in the secondary sector – and also the total potential supply of job seekers in the primary sector, since all workers search while employed in the secondary sector and on-the-job searching is taken to be as efficient as searching while unemployed.<sup>10</sup>

<sup>9</sup> The quadratic approximation is valid as long as  $L_S < h_1/h_{11}$ , to ensure that the marginal productivity of labor is positive. Similar restrictions also hold in Eq. (1).

<sup>10</sup> In practice, of course, being employed takes time away from search activities. Even then, however, it could be assumed that employment in the secondary sector conveys a positive signal to potential employers that would just offset the effect of a reduction in time available for searching on the efficiency of job search activities.

### 2.3. Equilibrium and unemployment

The first step in determining the equilibrium solution of the model requires calculating  $V_N^E$ , the expected lifetime utility of a skilled worker not employed in the primary sector, to determine  $\omega_E$ . As indicated before, a skilled worker who is not hired in the primary sector can either look for a job in the secondary sector (and supply the constant level of effort  $e_U$  if he is successful) or enter the unemployment pool and receive an unemployment benefit. The decision between these options depends on the perceived costs and benefits of remaining unemployed, compared to the potential reward from working in the secondary sector. The high-ability worker gets utility (per unit time) of  $\omega_U - e_U$  in secondary employment and a benefit of  $\Theta_E$  if unemployed.<sup>11</sup> We focus in what follows on the case where  $\omega_U - e_U > \Theta_E$ , which ensures that skilled workers who are unable to find a job in the primary sector will be looking for employment in the secondary sector.<sup>12</sup> As indicated earlier, the decision to look for a secondary sector job is necessary but not sufficient to actually find one, since employment may be demand constrained in that sector as well.

For simplicity, we follow Shapiro and Stiglitz (1984) in assuming that a skilled worker perceives the transition probabilities into a primary job out of unemployment or secondary sector employment as identical and equal to the hiring rate,  $\alpha$  – thus ignoring ‘deskilling’ or ‘demotivation’ effects associated with unemployment. The asset equation is thus given by

$$\rho V_N^E U E = (1 - u_E)(\omega_U - e_U) + \Theta_E u_E + \alpha(V_P^E - V_N^E), \quad (8)$$

where it is assumed that, in equilibrium, the no-shirking condition (3) holds with equality so that  $V_{Pn}^E = V_{Ps}^E = V_P^E$ . The quantity  $\alpha(V_P^E - V_N^E)$  in Eq. (8) is equal to the net expected utility gain of being employed in the primary sector, times the probability (per unit time) of being hired in that sector.

The second step consists in noting that in a steady-state equilibrium the flows of skilled workers in and out of employment in the primary sector must be equal.

<sup>11</sup> In practice, most unemployment benefit schemes phase out financial assistance gradually. The assumption that  $\Theta_E$  remains constant over time is, nevertheless, consistent with our focus on the steady state. We also abstract in what follows from the budget constraint that the government may face in financing the unemployment benefit scheme.

<sup>12</sup> The skilled worker contemplating searching for a job in the secondary sector compares the expected utility from searching, which is given by  $(1 - u_E)(\omega_U - e_U) + \mu_E \Theta_E$  – where  $u_E$  is the unemployment rate of skilled workers, so that  $1 - u_E$  is the probability of finding a job in the secondary sector – to the expected income while unemployed, which is  $\Theta_E$ . The condition that  $(1 - u_E)(\omega_U - e_U) + u_E \Theta_E > \Theta_E$  reduces to the condition given in the text.



Since on-the-job search is allowed, and searching while working in the secondary sector is as efficient as searching while unemployed, we have

$$b_E L_E^d = \alpha (\bar{L}_E - L_E^d), \tag{9}$$

where  $\bar{L}_E - L_E^d$  measures the total number of skilled workers looking for employment in the primary sector.

Solving Eqs. (2b) and (3) together with Eqs. (8) and (9) yields

$$\omega_E - e_E = (1 - u_E)(\omega_U - e_U) + \Theta_E u_E + \frac{e_E}{\pi} \left\{ \rho + \frac{b_E \bar{L}_E}{\bar{L}_E - L_E^d} \right\}, \tag{10}$$

which can be written as (see the Appendix):

$$\omega_E \equiv G(\omega_U), \quad G' > 0. \tag{11}$$

Eq. (11) indicates that to deter skilled workers from shirking, firms must pay a going wage sufficiently high relative to the secondary sector wage. An increase in  $\omega_U$  (for a given probability of finding employment in the secondary sector,  $1 - u_E$ ) raises the wage paid to high-ability workers, because it reduces the firing penalty. An increase in the unemployment benefit  $\Theta_E$  also raises skilled workers' wage.  $\omega_E$  is also higher the higher is the required effort in the primary sector, the higher is the turnover rate, the higher is the discount rate – since future losses incurred if caught shirking are less valued – and the lower is the probability of being caught shirking and subsequently fired.

Substituting Eqs. (5), (7) and (11) in Eq. (6) and maximizing profits with respect to wages and employment yields (see the Appendix):

$$MP_S \equiv h_1 - h_{11} L_S^d = \omega_U + \delta q, \tag{12a}$$

$$\omega_E = F(\omega_U), \quad F' < 0, \tag{12b}$$

where  $MP_S$  is the marginal productivity of labor in the secondary sector. Eq. (12b) represents a negative relationship between the equilibrium wage in the primary and secondary sectors, and is referred to as the *SLC* condition. Essentially, an increase in the efficiency wage paid in the primary sector tends to reduce the pool of 'good' (high-paying) jobs – thereby reducing turnover and enabling firms in the secondary sector to cut the wage offered in that sector.

Labor market equilibrium in this economy is thus characterized by five conditions: two conditions determining the levels of skilled and unskilled employment in the primary sector (Eqs. (4a) and (4b)), one condition determining the level of employment in the secondary sector (Eq. (12a)), and two wage-setting conditions for skilled workers and secondary sector workers (Eqs. (11) and (12b)). Unemployment may emerge in equilibrium if the wage in the secondary sector exceeds the wage associated with full employment.

The equilibrium is illustrated in Fig. 1. The North-West panel determines the skilled workers' wage  $\omega_E$  and the wage in the secondary sector  $\omega_U$ . The upward-sloping *NSC* curve depicts wage combinations that are consistent with the no-shirking condition for skilled workers (Eq. (11)), whereas the downward-slop-

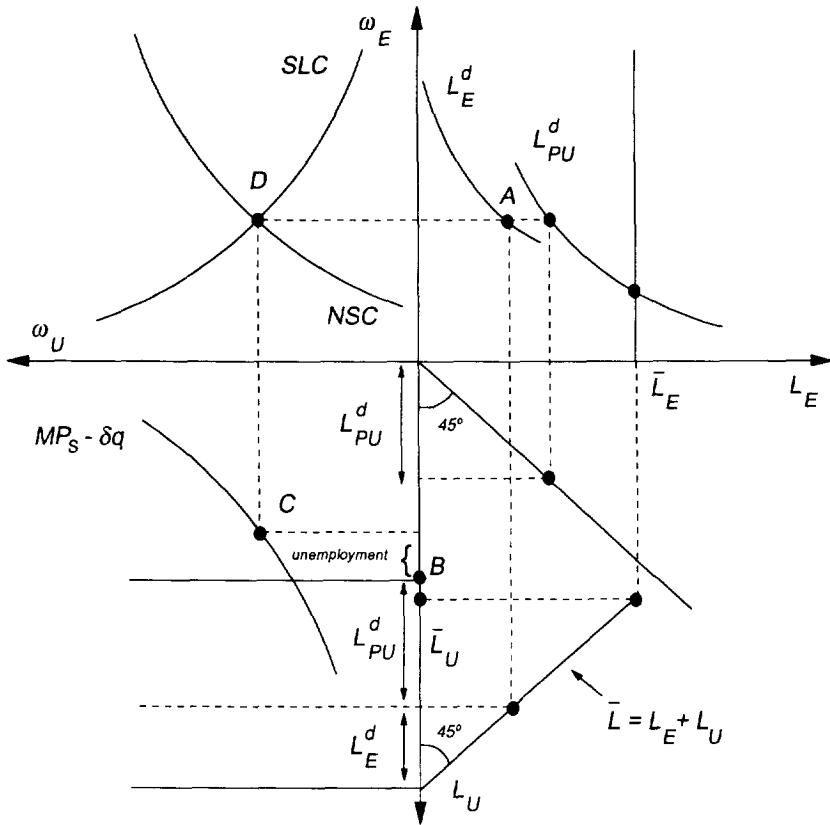


Fig. 1. Generalized unemployment equilibrium.

ing *SLC* curve depicts wage combinations that are consistent with optimal wage setting in the secondary sector (Eq. (12b)). Equilibrium values of  $\omega_E$  and  $\omega_U$  are determined at the intersection of these two curves (point *D*).<sup>13</sup> In the North-East quadrant of the diagram, the demand curves for skilled and unskilled workers in the primary sector are shown to be inversely related to the efficiency wage – reflecting our assumption that  $\sigma > 0$ . The supply constraint which results from the given size of the labor force is shown in the South-East quadrant. The supply of labor in the secondary sector consists of all workers (skilled and unskilled) who are unable to find employment in the primary sector. The 45 degree lines in that quadrant allows us to report the demand for skilled and unskilled labor in the primary sector from the North-East quadrant to the South-West quadrant. The

<sup>13</sup> Note that from Eq. (10) the secondary sector wage is always lower than the efficiency wage paid to skilled workers.



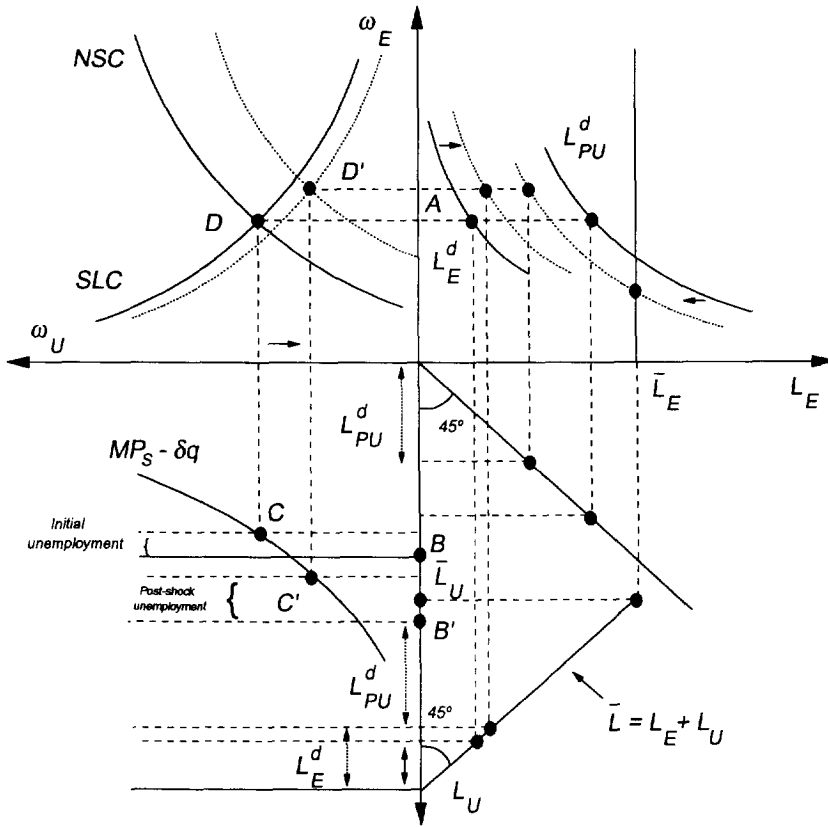


Fig. 3. Effect of a technological shock: General case.

examination of the long-run effects of technological shocks of this type. In our setup, a pro-skilled, anti-unskilled change in technology can be modeled as consisting of an increase in the parameter  $a_1$  coupled with a fall in the parameter  $a_2$  in the production function of the primary sector good, given by Eq. (1).

We will focus on the case where at the initial level of wages in the primary sector ( $\omega_E, \omega_U^*$ ) the ensuing aggregate change in the total demand for labor in the primary sector induced by the technological shock ( $da_1 > 0, da_2 < 0$ ) is zero, that is,  $d(L_{PU}^d + L_E^d) = 0$ . This specification implies that the marginal productivity curves of the two types of labor shift vertically by the same absolute amount, but in opposite directions. It thus rules out employment effects induced (at the initial level of wages) by a reduction in the demand for labor in the primary sector. Eqs. (4a) and (4b) imply therefore that the effect of the change in technology can be measured by

$$da_1/da_2 = -(a_{11} + \sigma)/(a_{22} + \sigma) < 0. \tag{13}$$

The effects of a technological shock of this type on relative wages, employment and unemployment are depicted in Figs. 2 and 3 (see the Appendix for technical details). The shock induces an outward shift in the demand for skilled workers, and an inward shift in the demand for unskilled labor in the primary sector, as shown in the North-East panel of the diagram. At the initial efficiency wage for skilled workers, the horizontal movement of the two curves is equal in absolute terms but occurs in opposite direction. The technological shock shifts both the *NSC* and *SLC* curves in the North-West quadrant rightward, as the demand for unskilled workers declines. Hence, the wage offered in the secondary sector also declines, as the employment prospects of unskilled workers in the primary sector deteriorate. The change in skilled workers' wage is in general ambiguous; in Fig. 2, it is shown to remain at its initial level. In this benchmark case, aggregate employment in the primary sector does not change, while the drop in wages in the secondary sector increases employment in that sector. Hence, the net effect is the reduction in 'good jobs' for unskilled workers in the primary sector, and net employment gains.

The last result is specific to the benchmark case, and Fig. 3 illustrates a case where the technological shock may induce higher unemployment. This may be the case if skilled workers' wage goes up, reducing thereby total employment in the primary sector, and increasing the pool of job seekers in the secondary sector.<sup>14</sup> The drop in the secondary sector wage and in turnover costs raises the demand for labor and induces higher employment in the secondary sector. Yet, if the increase in secondary sector employment falls short of the reduction in total employment in the primary sector, the ultimate outcome for the economy is higher unemployment.<sup>15</sup>

As can be inferred from the results presented in the Appendix, the strength of efficiency factors in the primary sector (as measured by the required level of effort

<sup>14</sup> To show that total employment in the primary sector will drop if  $\omega_E$  goes up, note that from Eqs. (4) and Eq. (13) we have

$$dL_{pU}^d / da_1 = -\frac{1}{a_{11} + \sigma} - \sigma \Delta^{-1} \left( \frac{d\omega_E}{da_1} \right), \quad dL_E^d / da_1 = \frac{1}{a_{11} + \sigma} - a_{22} \Delta^{-1} \left( \frac{d\omega_E}{da_1} \right),$$

which indicate that the effect of the technological shock on the employment level of each skill category can be decomposed in two parts. The first, measured by the term  $1/(a_{11} + \sigma)$ , is the direct effect. It reflects the replacement of unskilled labor by skilled labor. The second, indirect effect is proportional to  $d\omega_E / da_1$  in both equations, and results from the change in the wage paid to skilled workers. A higher efficiency wage induces a drop in demand for skilled labor, and changes demand for unskilled workers in that sector according to the sign of  $\sigma$ . Adding up the above equations yields

$$d(L_{pU}^d + L_E^d) / da_1 = -(a_{22} + \sigma) \Delta^{-1} \left( \frac{d\omega_E}{da_1} \right) < 0.$$

<sup>15</sup> Although not shown explicitly in Fig. 3 (to avoid further cluttering the graph) the curve  $MP_S - \delta q$  shifts downward in the South-West quadrant. This shift reflects the fact that the quit rate drops following the decline in total employment in the primary sector.

from skilled workers,  $e_E$ ) plays a critical role in determining the effect of the technological shock on wage dispersion, employment composition and unemployment. The higher the required level of effort from skilled workers, the larger will be the shift to the right of both the *NSC* and *SLC* curves, and thus the larger will be the fall in the secondary sector wage. The ultimate effect of the technological shock on skilled workers' wage depends on the initial unemployment rate. In the Appendix, we show that a higher initial unemployment rate will magnify the upward shift of the *NSC* curve, while mitigating the rightward shift in the *SLC* curve. The new technology will thus call for a higher compensation premium for skilled workers. As can be inferred from Eq. (10) and as explicitly shown in the Appendix, this higher premium can be generated either by reducing the secondary sector wage or by increasing the wage paid to skilled workers,  $\omega_E$ . However, a higher unemployment rate implies that a given drop in  $\omega_U$  is translated into a smaller increase in the skilled workers' premium, requiring thereby a higher  $\omega_E$ . While the net effect of the shift of the *NSC* and *SLC* curves on the secondary sector wage is in general ambiguous, the net effect on  $\omega_E$  is to increase it.<sup>16</sup> If this effect is large enough, the case depicted in Fig. 3 will prevail – that is, primary sector employment will contract, increasing thereby labor supply in the secondary sector and raising the prospect of higher unemployment.

In the Appendix we also consider the case where the technological shock shifts the marginal productivity curve of both skilled and unskilled labor proportionately, rather than by the same absolute amount, as considered in the foregoing discussion. It is shown there that the key implication of the previous experiment continues to hold: efficiency factors tend to magnify the effects of the technological shock on wage dispersion and unemployment. A general implication of the above analysis therefore is that the 'discipline device' for skilled workers consists of two elements: the wage differential between primary and secondary sector wages, and the unemployment rate, as emphasized in the original Shapiro–Stiglitz model.

#### 4. Summary and conclusions

This paper has studied the effects of technological shocks on relative wages, the distribution of the labor force, and unemployment. The analysis was based on the seminal model of efficiency wages developed by Shapiro and Stiglitz (1984), extended to incorporate technological differences across production sectors, labor force heterogeneity, minimum wage legislation, and turnover costs.

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<sup>16</sup> It is shown in the Appendix that the *SLC* curve may even shift leftward under certain conditions.

The first part of the paper presented the analytical framework, and showed that in equilibrium unemployment of both categories of workers may emerge. The second part of the paper focused on the effects of a technological shock that reduces productivity of unskilled labor while raising productivity of skilled workers – in such a way that employment in the primary sector, at the initial level of wages there, remains unchanged. It was shown that the effect of a shock of this type on the demand for unskilled labor in the primary sector is always negative, while the net effect on the demand for skilled labor reflects two conflicting factors: a direct technological effect (which is positive), and an indirect effect, which is negative and operates through changes in the efficiency wage earned by skilled workers. It was also shown that if efficiency considerations in the primary sector play a limited role, the technological shock has no effect on wages and no effect on total employment in the primary sector; employment of skilled workers rises by the same magnitude as the fall in employment of unskilled workers. When efficiency considerations are important, the adoption of the new technology raises the relative wage of skilled workers, reduces aggregate employment as well as the employment level of unskilled labor in the primary sector, and will in general raise the employment level of skilled workers. However, a higher required level of effort implies that the change in the demand for skilled labor is smaller, as the secondary effect offsets partially the direct, positive effect, and the level of employment of skilled workers may remain unchanged. The ultimate effect of the technological shock on skilled workers' wage depends also on the initial unemployment rate for that category of workers. Thus, the effect of technological shocks on skilled employment depends crucially on the strength of efficiency considerations in the primary sector and initial unemployment.

In a companion paper (Agénor and Aizenman, 1995) we have shown that efficiency factors continue to play an essential role in the transmission process of technological shocks if in the above setting secondary sector wages are assumed to be fully flexible.<sup>17</sup> Overall, therefore, a key feature of our analysis is that skilled-biased technological shocks may have an adverse effect not only on unskilled employment, but also on the employment rate of the skilled labor force. It may also help explain why technological shocks of this type lead to an increase in wage dispersion between unskilled workers with 'good' jobs and those with 'bad' jobs. Finally, our analysis in some sense corroborates the idea of 'hysteresis' in unemployment, since it predicts that the higher the initial unemployment rate, the higher the likelihood that skilled-biased technological shocks will further increase it.

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<sup>17</sup> We also examine in that paper the effects of asymmetric shocks (namely,  $da_1 > 0$  and  $da_2 = 0$ ; and  $da_1 = 0$  and  $da_2 > 0$ ), and the role of changes in unemployment benefits in mitigating the employment effects of technological shocks.

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### Appendix A

To solve the model, we begin by deriving the unemployment rate for each labor category. Let  $\Phi_E$  and  $\Phi_U$  be the employment shares of skilled and unskilled workers in the secondary sector. The following system summarizes the determination of  $\Phi_E$ ,  $\Phi_U$ ,  $u_E$  and  $u_U$ :

$$L_S^d = \Phi_U L_S^d + \Phi_E L_S^d, \quad \Phi_U + \Phi_E = 1; \quad (\text{A.1a})$$

$$\Phi_U L_S^d / (\bar{L}_U - L_{PU}^d) = \Phi_E L_S^d / (\bar{L}_E - L_E^d); \quad (\text{A.1b})$$

$$u_E = (\bar{L}_E - L_E^d - \Phi_E L_S^d) / \bar{L}_E, \quad (\text{A.1c})$$

$$u_U = (\bar{L}_U - L_{PU}^d - \Phi_U L_S^d) / \bar{L}_U. \quad (\text{A.1d})$$

Eq. (A.1b) indicates that the employment probability for skilled and unskilled workers looking for employment in the secondary sector are the same.

Solving this system gives us, for  $u_E$ :

$$u_E = \left( \frac{\bar{L}_E - L_E^d}{\bar{L}_E} \right) \left( \frac{\bar{L} - L_E^d - L_{PU}^d - L_S^d}{\bar{L} - L_E^d - L_{PU}^d} \right). \quad (\text{A.2})$$

Recall that the definition of the quit rate is

$$q = (b_U L_{PU}^d + b_E L_E^d) / (\bar{L} - L_E^d - L_{PU}^d). \quad (\text{A.3})$$

Consider now the derivation of (12b). Minimizing total unit labor costs ( $\omega_U + \delta q$ ) with respect to  $\omega_U$  yields

$$1 + \delta (dq/d\omega_E) (d\omega_E/d\omega_U) = 0, \quad (\text{A.4})$$

which indicates that in equilibrium, producers balance the direct effect of an increase in the wage (which is equal to unity) with the induced reduction in turnover costs. In calculating  $dq/d\omega_U$ , producers in the secondary sector are assumed to internalize the effect of a change in  $\omega_U$  on  $\omega_E$ , as can be inferred from Eq. (11).



Using Eqs. (4) and Eq. (A.3), assuming for simplicity that  $b_E = b_U = b$ , yields

$$dq/d\omega_E = -b(\sigma + a_{22})\bar{L}/\left[\Delta\left(\bar{L} - \tilde{L}_E^d - \tilde{L}_{PU}^d\right)^2\right], \tag{A.5}$$

and, from Eqs. (4) and Eq. (11):

$$\frac{d\omega_E}{d\omega_U} = \frac{1 - \tilde{u}_E}{1 + \frac{\gamma a_{22}}{\Delta} + \frac{\tilde{\omega}_U - e_U - \Theta_E}{\Delta} \left\{ \frac{A_2 a_{22}}{\bar{L}_E} + \frac{A_1 \tilde{L}_S^d (\sigma + a_{22})}{\left(\bar{L} - \tilde{L}_E^d - \tilde{L}_{PU}^d\right)^2} \right\}} \tag{A.6}$$

where a ‘ $\sim$ ’ denotes an initial value, and  $\Delta$  is defined right below Eqs. (4).  $A_1 = (\bar{L}_E - \tilde{L}_E^d)/\bar{L}_E$  and  $A_2 = (\bar{L} - \bar{L}_E^d - \tilde{L}_{PU}^d - \tilde{L}_S^d)/(\bar{L} - \tilde{L}_E^d - \tilde{L}_{PU}^d)$ , so that (from Eq. (A.2))  $\tilde{u}_E = A_1 A_2$ . Eq. (12b) is thus derived by substituting Eqs. (A.5) and (A.6) in Eq. (A.4). In explicit form, the equation is:

$$\begin{aligned} 0 &= \delta b \bar{L} (\sigma + a_{22}) (1 - \tilde{u}_E) - \left(\tilde{L} - \tilde{L}_E^d - \tilde{L}_{PU}^d\right)^2 \\ &\times \left\{ \Delta + \gamma a_{22} + (\tilde{\omega}_U - e_U - \Theta_E) \frac{A_2 a_{22}}{\bar{L}_E} \right\} \\ &- A_1 \tilde{L}_S^d (\sigma + a_{22}) (\tilde{\omega}_U - e_U - \Theta_E), \end{aligned} \tag{A.7}$$

where  $\gamma \equiv e_E b_E \bar{L}_E / \pi (\bar{L}_E - \tilde{L}_E^d)^2$ .  $\gamma$  may be viewed as measuring the importance of effort provided by skilled workers. Eq. (A.7) defines the *SLC* curve. It can be verified from that equation that the curve is downward-sloping.

We now determine the horizontal shift in the *NSC* and *SLC* curves, following the technological shock specified in Eq. (13). This is done by calculating the change in  $\omega_U$  while holding  $\omega_E$  constant. From Eq. (11) we therefore infer that

$$\left. \frac{d\omega_U}{da_1} \right|_{NSC} = - \frac{\gamma + A_2 (\tilde{\omega}_U - e_U - \Theta_E) / \bar{L}_E}{(1 - \tilde{u}_E) (\sigma + a_{11})}, \tag{A.8}$$

which shows that a higher  $\gamma$  and a higher initial unemployment rate of skilled workers (as measured by both  $A_2$  and  $\tilde{u}_E$ ) increase the induced horizontal shift of the *NSC* curve to a technological shock.

From Eq. (A.7), we have

$$\begin{aligned} \left. \frac{d\omega_U}{da_1} \right|_{SLC} &= - \frac{1}{\sigma + a_{11}} \left\{ \frac{2\gamma a_{22} (\bar{L} - \tilde{L}_E^d - \tilde{L}_{PU}^d)^2}{\bar{L}_E - Z_E^d} - \frac{\sigma + a_{22}}{\bar{L}_E} \right\} \\ &\cdot \left\{ A_1 \tilde{L}_S^d (\sigma + a_{22}) + \frac{A_2 a_{22}}{\bar{L}_E} (\bar{L} - \tilde{L}_E^d - \tilde{L}_{PU}^d)^2 \right\}^{-1}, \end{aligned} \tag{A.9}$$

Eqs. (A.8) and (A.9) imply that greater importance of efficiency factors (through  $\gamma$ ) will induce a greater shift of both curves to the right. Higher initial skilled unemployment will induce a greater shift of *NSC* to the right but a smaller shift of *SLC*.<sup>18</sup>

Finally, it is worth noting that our results continue to hold (in qualitative terms) if the technological shock takes a proportional form, rather than the form described in the text. Formally, consider the following modified production function in the primary sector (instead of Eq. (1)):

$$\begin{aligned} Q_P &= Q_P(L_E, L_{PU}; \Psi_E, \Psi_U) \\ &= (a_1 - 0.5a_{11}L_E)L_E\Psi_E + (a_2 - 0.5a_{22}L_{PU})L_{PU}\Psi_U \\ &\quad + \sigma L_E L_{PU} (\Psi_E \Psi_U)^{1/2}, \end{aligned} \quad (\text{A.10})$$

where  $\Psi_E$  and  $\Psi_U$  are technological shift parameters. It can be verified from (A.10) that a uniform relative increase in the shift parameters – so that  $d\log(\Psi_E) = d\log(\Psi_U)$  – is equivalent to a Hicks-neutral technological change. Profit maximization yields, instead of Eqs. (4):

$$L_E^d = \Delta^{-1}(a_1 - \omega_E/\Psi_E)a_{22} + \sigma(\Psi_E\Psi_U)^{-1/2}(\Psi_U a_2 - \omega_U^*), \quad (\text{A.11a})$$

$$L_{PU}^d = \Delta^{-1}(a_2 - \omega_U^*/\Psi_U)a_{11} + \sigma(\Psi_E\Psi_U)^{-1/2}(\Psi_E a_1 - \omega_E). \quad (\text{A.11b})$$

In a manner similar to Eq. (13), we have

$$\frac{d\Psi_E}{d\Psi_U} = - \frac{\omega_U^* a_{11} + \sigma(\omega_U^* + \omega_E + a_2 - a_1)/2}{\omega_E a_{22} + \sigma(\omega_U^* + \omega_E + a_1 - a_2)/2} \quad (\text{A.12})$$

A technological shock that raises  $\Psi_E$  and reduces  $\Psi_U$  in the proportions indicated in (A.12) would leave total employment in the primary sector constant at the initial level of wages there. The analysis described in Section 3 could be redone with this alternative specification of the technological shock. It is shown in an Appendix (available upon request) that the main insights derived with specification (13) continue to hold.

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<sup>18</sup> Note that in Eq. (A.9) if the initial unemployment rate of skilled workers  $\bar{u}_E$  is high and efficiency factors are not strong enough, the *SLC* curve may shift to the left.

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