2012

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DEPARTMENT OF ECONOMICS

Working Paper

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Working Paper 2012-5
(This is a revised version of 2010-03)

UNIVERSITY OF MASSACHUSETTS
AMHERST

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February 11, 2012

Abstract

This paper analyzes the effects of the minimum wage on wage inequality, relative employment and over-education. We show that over-education can be generated endogenously and that an increase in the minimum wage can raise both total and low-skill employment, and produce a fall in inequality. Evidence from the US suggests that these theoretical results are empirically relevant. The over-education rate has been increasing and our regression analysis suggests that the decrease in the minimum wage may have led to a deterioration of the employment and relative wage of low-skill workers.

JEL classification: J31, J41, J42

Key words: Minimum wage, earnings inequality, monopsony, efficiency wage, over-education.

*Early versions of this paper have been presented at the University of Massachusetts, University of Aarhus, Higher School of Economics, and Queen Mary University of London. We thank seminar participants for helpful comments. Perceptive comments and suggestions by an anonymous referee have been particularly helpful.

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1 Introduction

This paper analyzes the effects of changes in the minimum wage on wage inequality, relative employment and the prevalence of mismatch (over-education) in the labor market.

Studies by DiNardo et al. (1995) and Lee (1999) have suggested that changes in the minimum wage and other labor market institutions have been important for the observed increase in inequality. This claim has obvious appeal. It is easy to see how these institutional changes may have put downward pressure on low-skill wages. However, in a standard model the change in relative wages will raise the demand for low-skill workers. Contrary to this prediction, low-skill workers appear to have lost ground in terms of both wages and employment.

The simultaneous increase in the relative wage and employment of high-skill workers has been interpreted as evidence of skill-biased technical change (e.g. Levy and Murnane, 1992; Acemoglu, 2002). Other interpretations are possible, however: in this paper we show that a fall in the minimum wage can generate a deterioration in the position of low-skill workers, both in terms of wages and employment. The presence of mismatch is central to the argument. As shown by Sattinger (2006) and Skott (2005, 2006), relative wages and employment can move in the same direction, even in the absence of any skill bias, if the prevalence of mismatch is determined endogenously. Induced changes in mismatch, moreover, can contribute to an explanation of changes in within-group or residual inequality.

To keep matters as simple as possible, we assume that high-skill workers can get two types of jobs ('good' high-tech jobs and 'bad' low-tech jobs), whereas low-skill workers have only one type of employment opportunity (low-tech). We show that mismatch —some high-skill workers having low-tech jobs— is compatible with a variety of labor market theories, including extended versions of standard efficiency wage models in which the monitoring of workers' effort is imperfect, contracts are incomplete, and workers cannot convincingly pre-commit to not shirking. In this setting, one solution is for firms to use the threat of dismissal as a way to elicit effort (Shapiro and Stiglitz, 1984; Bowles, 1985). For this threat to work, both good and bad jobs must be rationed to ensure that employed workers receive a rent over and above their best alternative. Good jobs pay more than bad jobs, which in turn must pay more than unemployment. In equilibrium there will be both un- and under-employment (some high-skill workers have bad jobs that do not utilize their skills), and inequality between groups will depend not only on the wage gap between good and bad jobs, but also on the degree of mismatch. As long as some matches of high-skill workers and bad jobs are sustained in equilibrium, changes in exogenous variables will affect not only wages and employment rates but also the degree of mismatch. These induced changes in the degree of underemployment of high-skill workers lie behind the monopsonistic effects. An increase in the minimum wage can reduce the employment of high-skill workers in low-tech jobs, and this deterioration of the employment conditions for high-skill workers relaxes the no-shirking condition in high-tech jobs and stimulates employment.

Monopsonistic effects have been introduced into efficiency wage models by Rebitzer and Taylor (1995) but our mechanism is different. Rebitzer and Taylor assume that firms have fixed monitoring resources, so that the probability of detecting a shirking worker is decreasing in the total number of employees. Thus, firms are forced to increase wages, and thereby the potential penalty of dismissal, *pari-passu* with employment. In other words, firms face an upward sloping labor (effort) supply curve, and a binding minimum wage may induce an increase in employment, just as in the classical monopsony case. Unlike Rebitzer and Taylor, we have two different types of workers, and this heterogeneity, in combination with the presence of mismatch, implies that monopsonistic features can arise even with exogenously given probabilities of detection.[1] In our setting, unemployment, mismatch and monopsonistic effects are generated by the same efficiency-wage mechanism.[2]

The monopsonistic effects provide a link to another strand of literature. The monopsony model, literally interpreted, may have little relevance (for example see Stigler, 1946) but as argued by Manning (2003, 2004), labor markets can be monopsonistic, even if there is a multiplicity of buyers of labor. Indeed, the survey by Boal and Ransom (1997) describes several alternative multi-agent models that lead to many of the same conclusions as classic single-buyer monopsony. We contribute to this literature by showing that efficiency wages can generate economy-wide monopsony effects as well as skill mismatch.

The significance of the theoretical analysis depends on the degree of mismatch. While measuring mismatch has proved challenging, studies suggest that over-education is widespread in all OECD countries. Estimates range between 10 and 40%, and the evidence also shows large differences in the returns to education to different workers, depending on whether they are over- or under-qualified for their jobs (Sicherman, 1991; Groot and Maassen van den Brink, 2000)[3]. Combining data from the Dictionary of Occupational Titles and the Current Population Survey, our own estimates in this paper produce over-education rates of about 15-25% in the US, and the rate of over-education changes substantially between 1973 and 2002 (the period for which we have data).

Our theoretical model generates predictions for the effect of the minimum wage on unemployment, over-education, relative wages and relative employment. We estimate the relevant reduced-form equations using time series variation for the US as a whole and supplement these regressions with panel regressions using state-level data. This approach is unlike most recent empirical work on the employment effects of the minimum wage, which looks at specific groups or industries that are likely to be strongly affected, such as teenagers and restaurants (see Card and Krueger (1995), Dube et al. (2010), and Brown (1999) and Neumark and Wascher (2006) for surveys). Our theoretical argument, however, concerns macro effects on the entire labor market, and these macro effects can not be captured by a partial study of employment effects for a small subset of workers or industries. Nothing in our argument precludes adverse

[1]The model can be extended to include fixed monitoring resources, as in Rebitzer and Taylor. An appendix with this extension is available on request.

[2]This is unlike the analysis in Manning (2003, pp. 256–262), where efficiency wage elements and involuntary unemployment are added to models with monopsonistic features.

[3]Some studies have suggested that individual ability bias explains these results. Slonimczyk (2008), however, shows that differences in the returns to surplus and required qualifications persist when fixed effects are introduced. Slonimczyk (forthcoming) studies the effect of increasing skill mismatch on earnings inequality in the U.S.

employment effects in some industries or for some groups of workers.[4] The argument for positive employment effects in this paper is not that the individual employer has monopsonistic power and therefore increases employment and output in response to a rise in the minimum wage. Nor do we rely on inelastic demand for the output of sectors with a high proportion of low-skill workers.

The regression results are consistent with monopsonistic effects of changes in the minimum wage. The coefficient on minimum wages is either negative and significant or statistically not different from zero in all time series and panel regressions for low-skill and high-skill unemployment. We also find a strong inverse relationship between the minimum wage and the degree of over-education. Finally, the regressions give the expected negative effect of the minimum wage on the wage premium in high-skill jobs.

One obvious shortcoming of aggregate time series data is the small number of observations, in our case 96 quarterly observations over the period 1979–2002. The construction of a relevant minimum wage also raises problems since some state level minimum wages exceed the Federal minimum.[5] Panel data improves matters in some respects. The number of observations increases, the minimum wage can be defined at the state level, and the non-binding Federal level in some states —which is a problem in time series regressions— now becomes an advantage. But endogeneity issues, in particular with respect to the relative labor supply, lead to other problems.[6] These limitations and problems imply that the results should be interpreted with care.

The paper is in five sections. Section 2 describes the theoretical argument for endogenous mismatch. The effects of changes in a binding minimum wage are examined in Section 3. Section 4 presents the empirical evidence, and Section 5 concludes.

2 Endogenous mismatch

2.1 A benchmark without mismatch

Consider an economy with two types of jobs and two types of workers. Jobs are either high-tech or low-tech. Workers can be high-skill or low-skill; the level of skill is the product of past decisions to invest in human capital and is taken as given.

Firms maximize profits subject to a production function,

$$Y = F(N_H, N_L) \tag{1}$$

where N_H and N_L are the total number of high- and low-tech jobs that have been filled. There are constant returns to scale.

[4] The model in section 3 suggests that an increase in minimum wages may lead to expansion of employment of low-skill adult workers (their no-shirking condition has been relaxed), but the expansion may happen at the expense of both teenage workers and mismatched high-skill workers. This outcome would be in line with Neumark and Wascher's (2006) finding that an expansion of the earned income tax credits generate a displacement of teenage women by low-skill adult women.

[5] Changes in the coverage of the minimum wage could also be a potential source of difficulties. However, coverage was stable over the period that we consider.

[6] Changes in the minimum wage could also be partly endogenous (Card and Krueger, 1995; Autor et al., 2008). We address this issue in section 4.5.

Assuming perfect competition, the first order conditions with respect to the employment levels yield:

$$
\begin{aligned}
w_H &= F_1(N_H, N_L) && (2) \\
w_L &= F_2(N_H, N_L) && (3)
\end{aligned}
$$

where w_H and w_L denote the real wage rates in high and low tech jobs and F_i is the partial derivative with respect to argument i. The perfect-competition assumption could be relaxed. Imperfect competition with a constant markup on labor cost can be covered by including the same multiplicative constant on the right hand side of both (2) and (3); this would leave the qualitative results unchanged.

The first order conditions (2)–(3) can be combined with supply equations for the two types of labor. Let H and L be the numbers of low- and high-skill workers in the total labor force. If low- and high-skill workers are matched to low- and high-tech jobs, respectively, standard supply equations can be written as

$$
\begin{aligned}
\frac{N_H^s}{H} &= G^H(w_H); \quad G^{H'} \geq 0 && (4) \\
\frac{N_L^s}{L} &= G^L(w_L); \quad G^{L'} \geq 0 && (5)
\end{aligned}
$$

In equilibrium $N_H = N_H^s$ and $N_L = N_L^s$, and equations (2)–(5) determine solutions for the wages and employment.

2.2 A model with mismatch

It may be reasonable to assume that only trained doctors are hired by hospitals to do surgery, but one can wait tables, even with a Ph.D. degree. This possibility of mismatch between a worker's skill and the skill requirements of the job can be captured by allowing both types of workers to compete for the low-tech positions; we assume that high-tech jobs, by contrast, must be filled by high-skill workers. Algebraically,

$$
\begin{aligned}
N_H &= N_{HH} && (6) \\
N_L &= N_{LL} + N_{HL} && (7)
\end{aligned}
$$

where N_H and N_L denote high- and low tech jobs and N_{ij} is the employment of workers of type i in a jobs of type j $(i = H, L; j = H, L)$.

Assuming, for simplicity that high- and low-skill workers are perfect substitutes in low-tech jobs, the production function (1) and the first-order conditions (2)–(3) will be unaffected by the mismatch. The supply equations (4)–(5), however, are replaced by the following wage equations:

$$
\begin{aligned}
w_{HH} &= \phi^{HH}\left(\frac{N_{HH}}{H}, \frac{N_{HL}}{H}, w_L\right); \quad \phi_1^{HH} > 0, \phi_2^{HH} \geq 0, \phi_3^{HH} \geq 0 && (8) \\
w_{HL} &= \phi^{HL}\left(\frac{N_{HH}}{H}, \frac{N_{HL}}{H}, w_H\right); \quad \phi_1^{HL} > 0, \phi_2^{HL} \geq 0, \phi_3^{HL} \geq 0 && (9) \\
w_{LL} &= \phi^{LL}\left(\frac{N_{LL}}{L}, w_H\right); \quad \phi_1^{LL} > 0, \phi_2^{LL} \geq 0 && (10)
\end{aligned}
$$

Equation (8) gives the real wage in high-tech jobs as a function of the employment rate for high-skill workers in high- and low-tech jobs (N_{HH}/H and N_{HL}/H) and the wage rate for mismatched high-skill workers (w_L). Analogously, the wage equation for high-skill workers in low-tech jobs uses the employment rates and the wage rate for well-matched high-skill workers (w_H) as its arguments. Low-skill workers never get high-tech jobs and their wage equation (equation (10)) therefore contains only two arguments, their employment rate and the wage rate in high-tech jobs. Equations (8)–(10) are compatible with a range of labor market theories. A special case based on the Shapiro-Stiglitz model of efficiency wages is presented in detail in section 2.3. Wage bargaining models or norm-based theories of wage formation could also fit the equations, however: the bargaining power of workers in high-tech jobs, for instance, will depend on the arguments of the ϕ^{HH}-function, and wage norms typically take into account both the state of the labor the labor market and the wages received by other groups (e.g. Akerlof and Yellen, 1990; Skott, 2005). Standard Walrasian supply equations, finally, are special cases of (8)–(10).[7]

Equations (8)–(10) define three distinct wage rates. However, at an interior solution with both high- and low-skill workers in low-tech jobs, we must have

$$w_{HL} = w_{LL} = w_L \tag{11}$$

If equation (11) did not hold, profit maximizing firms would not hire both types of workers.[8] Trivially,

$$w_H = w_{HH} \tag{12}$$

since only high-skill workers have high-tech jobs.

Equations (6)–(12) can be combined with the first-order conditions (2)–(3) to solve for the levels of employment (N_H, N_{HL}, N_{LL}) and wages (w_H, w_L). The existence of interior solutions with mismatch depends on the precise specification of the equations.[9] We illustrate this possibility of interior solutions using the Shapiro-Stiglitz model.[10]

[7]If high- and low-tech jobs are equally attractive in all non-wage respects, standard supply functions can be written

$$\begin{aligned} w_{HH} &= w_{HL} = \tilde{\phi}^{HH}\left(\frac{N_{HH}+N_{HL}}{H}\right) \\ w_{LL} &= \tilde{\phi}^{LL}\left(\frac{N_{LL}}{L}\right) \end{aligned}$$

where $\tilde{\phi}^{HH}$ and $\tilde{\phi}^{LL}$ correspond to the inverses of the supply functions in equations (4)–(5), $(G^H)^{-1}$ and $(G^L)^{-1}$.

[8]For simplicity we have assumed that high- and low-skill workers can be substituted one-for-one. Differential productivity can be incorporated by defining the total employment in low-tech jobs as $N_L = N_{HL} + \lambda N_{LL}$ where λ represents the relative productivity of low-skill workers. This extension implies that $w_{HL} = \lambda w_{LL}$. All other results are unaffected.

[9]The benchmark in section 2.1 with $w_H > w_L$, which can be obtained as a special case (cf. footnote 7), has no interior solutions.

[10]The Shapiro-Stiglitz model was chosen partly because of its 'orthodox' character: using this model shows that fairness norms or other non-standard elements are not required to generate the results. Many of the assumptions of the model are clearly unrealistic but for present purposes we want stay as close as possible to the original formulation.

2.3 An extended Shapiro-Stiglitz model

Following Shapiro and Stiglitz (1984), an employed worker of type i in a job of type j gets a wage w_{ij} and instantaneous utility

$$u_{ij} = \begin{cases} w_{ij} - e_{ij} & \text{if not shirking} \\ w_{ij} & \text{if shirking} \end{cases}$$

where e_{ij} is the worker's disutility associated with exerting effort. Workers are risk neutral and discount future outcomes at the rate ρ.

Firms set wages to ensure that workers' best response is to exert effort. Monitoring is costly, and shirkers are detected (and fired) according to a positive but finite hazard rate (δ). The rate of job termination for non-shirking workers (p) is also positive and finite. Discount and termination rates are assumed constant across worker types.

These assumptions define three no-shirking conditions:

$$\begin{aligned} \rho V_{HH} &= w_{HH} - e_{HH} - p(V_{HH} - V_{HU}) && (13) \\ &= w_{HH} - (p+\delta)(V_{HH} - V_{HU}) \\ \rho V_{HL} &= w_{HL} - e_{HL} - p(V_{HL} - V_{HU}) + q_{HLH}(V_{HH} - V_{HL}) && (14) \\ &= w_{HL} - (p+\delta)(V_{HL} - V_{HU}) + q_{HLH}(V_{HH} - V_{HL}) \\ \rho V_{LL} &= w_{LL} - e_{LL} - p(V_{LL} - V_{LU}) && (15) \\ &= w_{LL} - (p+\delta)(V_{LL} - V_{LU}) \end{aligned}$$

where the V_{ij} are the value functions associated with each of the three employment states and q_{ijk} are transition rates for workers of type i in jobs of type j, and transitioning into job type k. Equations (13) through (15) incorporate the assumptions that low-skill workers get only low-tech jobs and high-skill workers prefer high-tech jobs (the transition rates q_{HHL} and q_{LLH} are zero). If the no-shirking conditions are binding, equations (13)–(15) imply that

$$\begin{aligned} V_{HH} - V_{HU} &= \frac{e_{HH}}{\delta} && (16) \\ V_{HL} - V_{HU} &= \frac{e_{HL}}{\delta} && (17) \\ V_{LL} - V_{LU} &= \frac{e_{LL}}{\delta} && (18) \end{aligned}$$

Assuming the flow of instantaneous utility is zero when unemployed, the value functions for unemployed workers are given by:

$$\begin{aligned} \rho V_{HU} &= q_{HUH}(V_{HH} - V_{HU}) + q_{HUL}(V_{HL} - V_{HU}) && (19) \\ \rho V_{LU} &= q_{LUL}(V_{LL} - V_{LU}) && (20) \end{aligned}$$

Using equations (13)–(20) and assuming that the transition probabilities for a high-skill worker into high-tech jobs are the same independently of whether the worker is unemployed or under-employed ($q_{HUH} = q_{HLH} = q_{HH}$), we can solve for wages:

$$w_{HH} = e_{HL}\frac{\delta+\rho+p+q_{HH}+q_{HUL}}{\delta} + +(e_{HH}-e_{HL})\frac{\delta+\rho+p+q_{HH}}{\delta} \tag{21}$$

$$w_{HL} = e_{HL}\frac{\delta+\rho+p+q_{HH}+q_{HUL}}{\delta} \tag{22}$$

$$w_{LL} = e_{LL}\frac{\delta+\rho+p+q_{LUL}}{\delta} \tag{23}$$

Given the termination rates for shirkers and non-shirkers and a constant supply of both types of workers (H, L), all transition probabilities (q) can be determined through steady state conditions that depend only on employment levels. In a steady state, the unemployment rates and the rate of mismatch are constant, and entries and exits from each of the employment states are balanced. Formally:

$$q_{HH}(H-N_H) = pN_H \tag{24}$$

$$q_{HUL}(H-N_H-N_{HL}) = pN_{HL}+q_{HH}N_{HL} \tag{25}$$

$$q_{LUL}(L-N_{LL}) = pN_{LL} \tag{26}$$

Using (24)–(26), the wage equations (the no-shirking conditions) can be written

$$w_{HH} = e_{HL}\frac{\delta+\rho+p\frac{H}{H-N_H-N_{HL}}}{\delta} +(e_{HH}-e_{HL})\frac{\delta+\rho+p\frac{H}{H-N_H}}{\delta} \tag{27}$$

$$w_{HL} = e_{HL}\frac{\delta+\rho+p\frac{H}{H-N_H-N_{HL}}}{\delta} \tag{28}$$

$$w_{LL} = e_{LL}\frac{\delta+\rho+p\frac{L}{L-N_{LL}}}{\delta} \tag{29}$$

The no-shirking conditions (27)–(29) fit the general wage equations (8)–(10). Using (11)–(12), it is readily seen that the two groups of workers will have the same unemployment rates ($u_H = \frac{H-N_H-N_{HL}}{H} = \frac{L-N_{LL}}{L} = u_L$) if $e_{HL} = e_{LL}$. Empirically, unemployment rates for low-skill workers are higher than for high-skill workers, and we assume $e_{LL} > e_{HL}$. The same equations show that the two unemployment rates must move together. From the wage equations it follows, finally, that high-tech jobs pay a higher wage than low-tech jobs if $e_{HH} > e_{HL}$;[11] we assume this condition is met.

As shown by Skott (2006), this model can generate seemingly paradoxical effects. Neutral shifts in the production function may affect the relative wage and the relative

[11] A similar result could be obtained with equal levels of effort disutility but different detection rates of shirkers ($\delta_{HL} > \delta_{HH}$).

employment rate of high-skill workers in the same direction and, moreover, because it hurts the employment prospects of low-skill workers, an increase in the supply of high-skill labor can lead to an increase in the skill premium.

3 Minimum wages

Now introduce a binding constraint on the low-tech wage. The constraint could come directly from a minimum wage that is set above the equilibrium solution for w_L, or the constraint could be interpreted more broadly. The general wage equations in section 2.2 may reflect norms of fairness that evolve over time. Some changes in the norms may be autonomous —broad ideological shifts may lead to increased tolerance of wage inequality and employer 'greed'. Others may be triggered by particular events. Thus, the minimum wage is likely to be an important reference point for wages at the low end of the spectrum. Its rise may give firms an incentive to adjust wages, even for low-paid workers with wages above the minimum wage, in order to avoid adverse effects on morale, productivity and labor turnover. In short, only a relatively small proportion of the labor force is directly affected by the minimum wage but a much broader group may be affected indirectly.

Although in what follows we shall refer to the binding constraint simply as the minimum wage, the broader interpretation should be kept in mind. Our low-tech jobs should be seen as an aggregate of different low paying jobs with wages that move together and are influenced by the minimum wage.

3.1 General effects

We are interested in the effects of an increase in the minimum wage ($\underline{w}$) on employment and wages. With constant returns to scale, an increase in one of the real wage rates must be associated with a decline in the other wage.[12] By assumption the minimum wage is binding for low-tech jobs, and an increase in the minimum wage must therefore reduce the wage in high-tech jobs.

$$w_L = \underline{w} \tag{30}$$

$$w_H = \zeta(\underline{w}); \qquad \zeta' \leq 0 \tag{31}$$

Using the first-order conditions (2)–(3), the resulting decline in the wage ratio w_H/w_L generates an increase in the employment ratio N_H/N_L:

$$N_H = \eta(\underline{w})N_L = \eta(\underline{w})(N_{LL} + N_{HL}); \quad \eta' \geq 0 \tag{32}$$

The general conclusions summarized by equations (31)–(32) are based on the production function and firms' first order conditions (2)–(3); they are independent of the

[12] Assume that both wages at the new equilibrium were greater than or equal to the wages at the original equilibrium (with at least one strict inequality). In this case real unit labor costs must have increased which contradicts the assumption of a constant markup on labor costs (under perfect competition the markup is unity and the argument can be phrased differently: if firms satisfy the zero-profit constraint at the new equilibrium, they would have been able to make positive profits at the initial configuration of wage rates, and the initial position could not have been an equilibrium).

wage equations. Additional results, however, require assumptions about the nature and extent of mismatch in the labor market.

3.2 Minimum wages and induced mismatch

Without mismatch, a decline in w_H implies a fall in N_H (see equation (4)). Since the employment ratio N_H/N_L rises, low-skill employment must also fall.[13] This conclusion holds whenever the relevant 'supply curve' for high-skill labor is upward sloping and independent of the minimum wage.

Things become more complicated when there is mismatch. In the Shapiro-Stiglitz model, if the minimum wage is binding then, by definition, the no-shirking condition cannot be binding for both high- and low-skill workers in low-tech jobs. It may be binding for one or the other, but the minimum wage only has bite if firms could fill a larger number of low-tech jobs with non-shirking workers at an unchanged wage.[14] We consider two polar cases. In the first case, the no-shirking condition is always binding for low-skill workers; in the second case it is always binding for high-skill workers.

In his study of wage setting behavior, Bewley (1999) found that overqualified job applicants were common but that many employers were reluctant to hire them. Indeed, this "shunning of overqualified job applicants" is highlighted as one of two novel findings of the study (p.18). Attitudes to overqualified applicants differed somewhat between primary and secondary sector jobs, where secondary sector jobs are defined as short-term positions that are often part time. Both sectors received applications from overqualified workers, but 70 percent of firms expressed a "total unwillingness" to hire them for primary sector jobs, 10 percent were "partially unwilling" and only 19 percent were "ready to hire" overqualified applicants (pp. 282–83). Two main reasons account for the negative attitude to overqualifications: a concern that applicants would quit again as soon as possible and a concern that applicants would be unhappy on the job. Secondary sector employers had fewer reservations, but only a minority (47 percent) "were ready to hire them" with 30 percent being "totally unwilling" and 23 percent "partially unwilling" (p. 324).

Bewley's findings support our first case: they suggest that firms may prefer low-skill workers in low-tech jobs if both high- and low-skill workers are available at the same wage cost. Büchel (2002), however, suggests that "over-educated workers are generally more productive than others" and that, because of this, "firms hire over-educated workers in large numbers." This claim would seem to support our second case.

3.2.1 Case 1: Mismatch with low-skill workers preferred in low-tech jobs

When firms prefer low-skill workers in low-tech jobs, the Shapiro-Stiglitz model implies that high-skill workers will only be hired for low-tech jobs if the no-shirking condition

[13] A completely inelastic supply curve for high-skill labor means that high-skill employment is unaffected by an increase in the minimum wage; low-skill employment still falls.

[14] The argument also applies to the general wage equations (9)–(10). If the minimum wage is binding, the wage equations for high- and low-skill workers in low-tech jobs cannot both be satisfied. One of the groups must be rationed.

is binding for low-skill workers.[15] Thus, the no-shirking condition for low-skill workers is satisfied as an equality while the minimum wage exceeds the expression for w_{HL} in (28).

Since the no-shirking condition for high-skill workers in low-tech jobs fails to be satisfied as an equality, equation (17) no longer holds. Instead —using (13), (14), and (19)— we have

$$V_{HL} - V_{HU} = \frac{\underline{w} - e_{HL}}{\rho + p + q_{HH} + q_{HUL}} = \frac{\underline{w} - e_{HL}}{\rho + p\frac{H}{H - N_H - N_{HL}}} \tag{33}$$

and the no-shirking conditions for high-skill workers in high-tech jobs and low-skill workers can be written,

$$\begin{aligned} w_H &= \frac{\delta(\underline{w} - e_{HL})}{\rho + p\frac{H}{H-N_H-N_{HL}}} \frac{\delta + \rho + p\frac{H}{H-N_H-N_{HL}}}{\delta} + \\ &\quad + (e_{HH} - \frac{\delta(\underline{w} - e_{HL})}{\rho + p\frac{H}{H-N_H-N_{HL}}}) \frac{\delta + \rho + p\frac{H}{H-N_H}}{\delta} \qquad (34) \\ \underline{w} &= w_L = e_{LL} \frac{\delta + \rho + p\frac{L}{L-N_{LL}}}{\delta} \qquad (35) \end{aligned}$$

Equation (35) shows that N_{LL} will increase following a rise in the minimum wage, that is, low-skill workers will benefit both in terms of wages and employment. This important result is quite intuitive. By assumption the no-shirking condition represents the binding constraint on low-skill employment, and an increase in the minimum wage relaxes this constraint. A higher minimum wage may also affect the number of low-tech jobs but that has no effect on low-skill employment as long as some low-tech jobs are filled with high-skill workers.

The solution for N_H and N_{HL} is not quite as simple. The high-tech wage and the ratio of high-tech to low-tech jobs are determined, as before, by the first order conditions (2)–(3), and the values of N_H and N_{HL} can be derived using (34) and the definitional relation

$$N_H = \frac{N_H}{N_L}(N_{HL} + N_{LL}) \tag{36}$$

The effect of a rise in $\underline{w}$ on N_H is ambiguous. There may be a negative effect on the number of high-skill jobs, not surprisingly, but a positive effect on N_H can be obtained if N_{LL} is elastic and an increase in w_L generates a large decrease in N_{HL}.

An increase in N_H is a necessary condition for other interesting effects. The employment ratio N_H/N_L must rise, but with an increase in N_H this condition can be satisfied, even with an increase in N_L. An increase in both N_L and N_H, moreover, implies that aggregate employment must also increase. These monopsonistic effects are made possible because a rise in minimum wages relaxes the no-shirking constraint

[15] Appendix A outlines the effects of minimum wages using the more general wage equations in section 2.1.

Table 1: Employment and wage effects of changes in the minimum wage when firms prefer low-skill workers in low-tech jobs

$\underline{w}$	N_{LL}	N_{HL}	N_L	N_H	w_H	Ω	N	$\frac{w_{HA}}{\underline{w}}$	Θ
1.7	0.03	0.58	0.62	0.29	3.68	0.64	0.9	1.38	0.40
1.8	0.30	0.35	0.67	0.35	3.47	0.37	1.02	1.45	0.32
1.9	0.45	0.23	0.67	0.39	3.29	0.21	1.06	1.46	0.24
2.0	0.54	0.11	0.66	0.42	3.13	0.10	1.08	1.44	0.16
2.1	0.61	0.02	0.63	0.45	2.98	0.02	1.08	1.40	0.06

Note: Authors' simulation based on the following parameter values: $L = H = 1$, $e_{LL} = 1.3$, $e_{HL} = 0.5$, $e_{HH} = 2$, $Y = 5N_H^{0.5}N_L^{0.5}$, $\rho = 0.1$, $\delta = 1$, $p = 0.2$.

for low-skill workers, and as the employment of high-skill workers in low-tech jobs decreases, there is a derived effect on the no-shirking condition for high-skill workers in high-tech jobs.

The monopsonistic outcome is illustrated by the numerical example in Table 1. The production function is taken to be Cobb-Douglas and the parameters of the utility function are chosen to ensure that $w_H > w_L$. Given the parameters and initial values, an increase in the minimum wage raises N_{LL}, N_H and N; low-tech employment N_L first rises and then drops back to roughly its initial level. The displacement of high-skill workers from low-tech jobs is also shown in Table 1: the increase in $\underline{w}$ reduces the degree of over-education (Ω). The average wage premium is increasing in w_H/w_L but decreasing in Ω, and the net effect is a non-monotonic relation with the minimum wage, increasing for some values of the minimum wage but falling if the minimum wage is raised beyond a certain point. An increase in $\underline{w}$, finally, reduces within group inequality (Θ).[16]

3.2.2 Case 2: Mismatch when firms prefer high-skill workers in low-tech jobs

In this case firms only hire low-skill workers if the no-shirking condition is binding for high-skill workers in low-tech jobs. Algebraically, the wage rates satisfy the following equations:

[16]These variables are defined as follows:

$$\begin{aligned}
\Omega &= \frac{N_{HL}}{N_H + N_L} \\
\frac{w_{HA}}{w_L} &= \frac{\frac{N_{HL}}{N_H+N_{HL}}w_L + \frac{N_H}{N_H+N_{HL}}w_H}{w_L} \\
\Theta &= \sqrt{\frac{N_{HL}}{N_H + N_{HL}}(\frac{w_L - w_{HA}}{w_{HA}})^2 + \frac{N_H}{N_H + N_{HL}}(\frac{w_H - w_{HA}}{w_{HA}})^2}
\end{aligned}$$

Table 2: Employment and wage effects of changes in the minimum wage when firms prefer high-skill workers in low-tech jobs

$\underline{w}$	N_{LL}	N_{HL}	N_L	N_H	w_H	Ω	N	$\frac{w_{HA}}{\underline{w}}$	Θ
1.61	0.86	0.39	1.25	0.52	3.88	0.22	1.77	1.81	0.39
1.64	0.50	0.48	0.99	0.42	3.81	0.34	1.41	1.62	0.41
1.67	0.03	0.62	0.65	0.29	3.74	0.66	0.94	1.40	0.41

Note: Authors' simulation based on the following parameter values: $L = H = 1$, $e_{LL} = 0.2$, $e_{HL} = 0.5$, $e_{HH} = 2$, $Y = 5N_H^{0.5}N_L^{0.5}$, $\rho = 0.1$, $\delta = 1$, $p = 0.2$.

$$w_H = e_{HL}\frac{\delta + \rho + p\frac{H}{H-N_H-N_{HL}}}{\delta} + (e_{HH} - e_{HL})\frac{\delta + \rho + p\frac{H}{H-N_H}}{\delta} \quad (37)$$

$$\underline{w} = w_{HL} = e_{HL}\frac{\delta + \rho + p\frac{H}{H-N_H-N_{HL}}}{\delta} \quad (38)$$

From profit maximization we know that an increase in $\underline{w}$ leads to a decline in w_H and an increase in N_H/N_L. Equations (37)–(38) now imply that N_H must fall (substitute (38) into (37) and use the fact that $w_H - \underline{w}$ decreases) and hence that N_L declines.

These implications are qualitatively the same as in the case without mismatch. The presence of mismatch, however, adds a few extra results. Using (38), it follows that a rise of $\underline{w}$ will increase aggregate employment of high-skill workers ($N_H + N_{HL}$). Hence, the decline in low-skill employment ($N_{LL} = N_L - N_{HL}$) is exacerbated, the proportion of mismatched high-skill workers ($N_{HL}/(N_H + N_{HL}$) and the degree of over-education (Ω) go up, and the wage premium, $w_{HA}/\underline{w}$ will fall. Total employment ($N = N_H + N_L$) must decrease since N_H/N_L increases and N_H falls.

According to this case, the fall in minimum wages since the 1970s should have led to increases in high-tech wages and the wage premium; the number of high-tech jobs should also have increased but over-education should have dropped, as should total employment of high-skill workers and within-group inequality; low skill workers should have seen an increase in employment. Numerical results are given in Table 2.[17]

4 Evidence

In this section we look at how the theoretical predictions of the model hold up against the available evidence. We first introduce the data and provide a descriptive analysis of the main trends in employment and earnings. This is followed by the estimation of reduced form equations derived from the model.

[17] With one exception, the benchmark parameters are the same as in Table 1. The exception is the cost of effort for low-skill workers which has been changed to $e_{LL} = 0.2$ (compared to $e_{LL} = 1.3$ in Table 1). The value of e_{LL} does not affect the solution for low-skill employment, but a lower value of e_{LL} is used to ensure that the no-shirking constraint is satisfied for low-skill workers at the implied levels of N_{LL} and $w_L = \underline{w}$.

4.1 Measuring mismatch and match premia

The empirical relevance of the analysis in the previous section depends on the extent of mismatch in the labor market. It is notoriously difficult to measure skill requirements but the best existing source for the U.S. is the Dictionary of Occupational Titles (DOT). The DOT reports expert assessment of more than $12,000$ job titles. We take the General Education Development (GED) index as our measure of skill requirements. The GED ranks jobs in a scale of 1 to 6 (a GED of 4 roughly represents the skills acquired through high-school). Jobs with GED greater than 4 are considered high-tech.

Unfortunately, the very detailed job classification of the DOT is not available in any representative survey of earnings. We use the average GED over 3-digit occupations as a proxy measure.[18] The analysis is thus restricted to the period 1973–2002, during which the 1970 and 1980 census occupational classifications were in use. During this period there were two data issues of the DOT: 1977 and 1991. Other years are obtained through linear extrapolation.

The skill requirements data were merged with the Current Population Survey (CPS) earnings files. We use the education item to identify low- (high school or less) and high-skill workers (at least some college). Figure 1 shows the distribution of employment across job and skill levels over the period. The graph confirms the well studied movement toward higher levels of education attainment. The share of employed workers with at least some college went from around 33% in 1973 to over 58% in 2002. Less well known is the steady increase in the share of high skill workers whose jobs have requirements below their skill level, at least according to the DOT experts. At the beginning of the period only 14.7% of workers were in this category; toward the end of the period the percentage of over-educated workers had increased by 10 percentage points.

There are two potential objections to the finding of substantial and growing skill mismatch in the U.S. economy. First, education attainment could be a poor measure of skill supply if there have been significant changes in the quality of education and some SAT scores show a slightly declining trend. The SAT scores, however, have a downward bias because of the significant increase in the participation rate in these tests (Grissmer, 2000). The more representative NAEP scores show minor fluctuations but no sustained decline since the 1970s in the performance of high-school students (Stedman, 2009).[19]

Second, the DOT-GED index might not be a reliable measure of skill requirements. Table B.2 in the appendix summarizes information on skill requirements for the top 25 3-digit occupations in 2002. The information in the table provides an idea of the evolution of the GED and two other DOT-based indexes during the period when the 1980 occupational classification was in use. Both the "Direction, Control, Planning" (DCP) and the "Set Limits, Tolerances, or Standards" (STS) are consistent with the GED in showing little or no change in skill requirements between 1983 and 2002. It could be the case, however, that all DOT-based measures are biased. The last

[18] The GED scores and other DOT measures are generously made publicly available by David Autor.

[19] Handel (2003) relates the evidence to the debate on skill requirements and mismatch.

comprehensive revision of the DOT scores was prepared for the third edition (1977). The 4th edition (1991) relied heavily on the third edition scores and surveyed workers in a small number of high tech sectors. For this reason, we collected descriptions of education requirements from the 'Training, Other Qualifications, and Advancement' section in the 1983 and 2002 editions of the Occupational Outlook Handbook (U.S. Bureau of Labor Statistics, 1982, 2002). Almost without exceptions, these descriptions confirm the finding of stable educational requirements (see table B.2).[20]

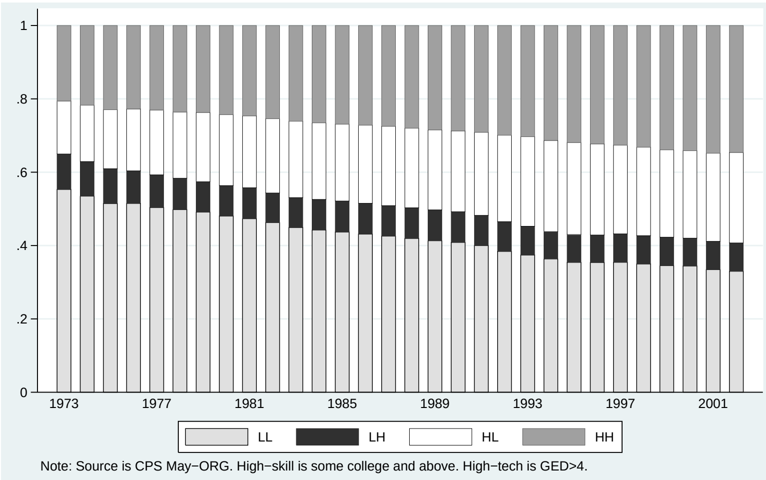

Figure 1: Distribution of the Employed Labor Force

Do job types matter for earnings, conditional on education attainment? To answer this question we construct a wage sample from the CPS files. In 1973–78 earnings questions were asked to the whole CPS sample in May.[21] Our earnings variable is real weekly earnings divided by usual weekly hours, unless a separate and higher hourly rate is also reported. Earnings are deflated using the CPI (1979 = 100). The wage sample contains all wage and salary workers employed full time who are between 18 and 65 years of age. We weight the CPS data by hours worked and the appropriate sampling weight. The CPS has undergone several changes that reduce its consistency over time; details on the necessary adjustments on earnings and other variables are provided in appendix B.

Figure 2 shows average real wages for workers separated into the same four groups. Wages of high skill workers in high-tech jobs clearly stand out as higher than those

[20] Our findings are consistent with other assessments. Drawing on data from the Quality of Employment Survey, the Panel Study of Income Dynamics and the Survey of Workplace Skill, Technology, and Management Practices (STAMP), Handel (2010, p.22) concludes that "there is little support for the idea that skill upgrading has proceeded at an especially rapid pace in recent years." See Handel (2008) for details on the STAMP data and methodology.

[21] Starting in 1979, earnings questions are asked every month to roughly a fourth of the sample (the outgoing rotation groups). One important implication is that, in order to exploit quarterly variation in the minimum wage, the regression analysis is restricted to the period 1979-2002. A previous version of this paper used yearly frequencies for the whole 1973–2002 period and obtained qualitatively identical results.

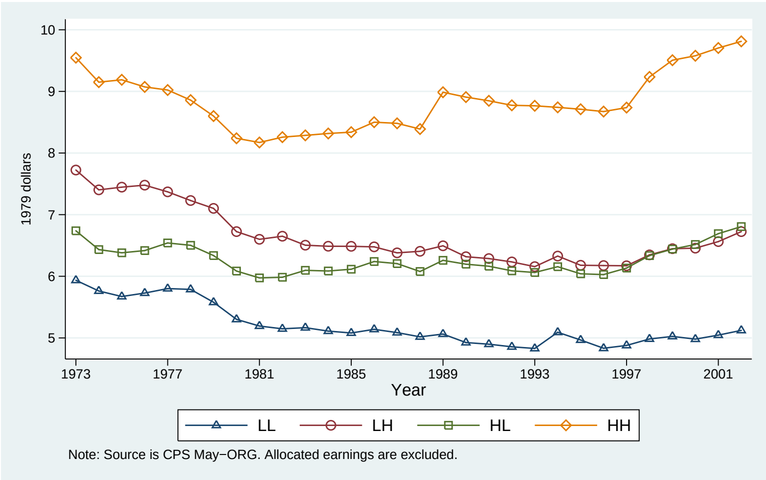

Figure 2: Average Earnings of Full-time Workers

of all other groups. Low skill workers in the low-tech sector are at the bottom of the earnings distribution.[22]

4.2 Unemployment and mismatch

The analysis in section 3 generates reduced-form equations of the form

$$u_L = f(\underline{w}, \frac{H}{L}) \tag{39}$$

$$u_H = g(\underline{w}, \frac{H}{L}) \tag{40}$$

$$\Omega = h(\underline{w}, \frac{H}{L}) \tag{41}$$

This general representation covers both cases 1 and 2, but the precise form of the equations depends on whether firms prefer high- or low-skill workers in low-tech jobs. The expression for u_L, for instance, simplifies to $u_L = f(\underline{w})$ in case 1 (firms prefer low-skill workers in low-tech jobs) and the expression for u_H to $u_H = g(\underline{w})$ in case 2 (firms prefer high-skill workers in low-tech jobs).

Our regressions use log-linear versions of these equations but also include a time trend to allow for the effects of technical change:

[22]The stylized model in section 3 has only two job categories and two skill levels, and this and other simplifying assumptions imply that $N_{LH} = 0$ and $w_{HL} = w_{LL}$. These strong predictions will not hold if the simplifying assumptions are relaxed. With a range of jobs and skills, for instance, college educated workers with low-tech jobs may hold jobs that are, on average, better than the average job of correctly matched low-skill workers; analogously, undereducated low-skill workers get high-tech jobs but the distribution of these jobs may not be the same as the distribution of the jobs held by correctly matched high-skill workers.

$$u_L = \gamma_0 + \gamma_1 t + \gamma_2 \log \underline{w} + \gamma_3 \log \frac{H}{L} \tag{42}$$

$$u_H = \delta_0 + \delta_1 t + \delta_2 \log \underline{w} + \delta_3 \log \frac{H}{L} \tag{43}$$

$$\Omega = \rho_0 + \rho_1 t + \rho_2 \log \underline{w} + \rho_3 \log \frac{H}{L} \tag{44}$$

It is not possible to identify the structural parameters of the model from these reduced forms, but the model implies the following parameter restrictions in cases 1 and 2:[23]

- Case 1: $\gamma_2 < 0, \gamma_3 = 0, \delta_2 \gtreqless 0, \delta_3 \gtreqless 0, \rho_2 < 0, \rho_3 > 0;$[24]
- Case 2: $\gamma_2 > 0, \gamma_3 < 0, \delta_2 < 0, \delta_3 = 0, \rho_2 > 0, \rho_3 = 0.$[25]

We estimate these equations using quarterly data for the period 1979–2002.[26] One possible strategy is to estimate equations (42)–(44) using time series variation for the whole sample. This approach has the advantage of being closest in spirit to the macro model in section 3. The obvious drawback is that it leaves us with only 96 observations. Also, states have the ability —which they often use— to set a minimum wage that is above the federally mandated. Therefore, it is difficult to construct a good measure of the minimum wage at the national level. An alternative strategy is to treat each state as a separate economy. This approach yields a balanced panel of 51 units, dramatically increasing degrees of freedom. It also allows for each state to have its own minimum wage. However, the U.S. labor market is known to be highly mobile and interconnected, and conditions that allow identification at the national level might not hold for states. In particular, our specifications treat the relative share of skilled workers (H/L) as exogenous. This assumption is more likely to hold at the national level since workers already in the work force find it costly to adjust their skill levels and adjustment through new entries is slow. It is harder to make the same case at the state level. Workers can commute or move to the states offering the best prospects for employment and wages. If H/L is endogenous, the reduced form specification should drop this variable. We offer this alternative specification as a robustness check in our tables below.

Tables 3–5 report the estimates of the reduced form regressions (42)–(44). Columns (1)–(2) in Tables 3–4 and (1)–(3) in Table 5 contain time series estimates while columns (3)–(5) in Tables 3–4 and (4)–(8) in Table 5 contain panel regressions using state level data. We estimated the time series regressions using both OLS and

[23] These restrictions do not depend on the specifics of the Shapiro-Stiglitz model. They hold for the general framework in section 2.2. For example, the case 1 restrictions follow directly from equations (52) and (54) in appendix A.

[24] The ambiguity of the sign of δ_2 in case 1 was discussed in section 3. The sign of δ_3 is ambiguous for related reasons. An increase in H/L reduces N_H/H but raises N_{HL}/H, and the unemployment rate can go either way. The analytics are messy, but simulations confirm the result.

[25] These parameter signs follow from equations (27)–(28).

[26] Table B.1 in the appendix provides descriptive statistics on the variables used in the analysis.

GLS-AR(1), since for both unemployment rates the Durbin-Watson test-statistic rejects the null of no first order autocorrelation in the error term at the 5% significance level. For the over-education rate the same test falls in the inconclusive region. The equation for over-education was estimated with and without a cyclical correction (the deviation of unemployment from its trend). Reassuringly, all these different variations in the precise specification had only minor effects on the coefficient estimates.

Looking first at the time series results, we find no evidence that a rise in the minimum wage will be associated with increased unemployment (for low-skill workers the estimate is negative and insignificant). We also find evidence that an increase in the minimum wage reduces over-education. These results are consistent with case 1, where firms prefer to hire low-skill workers in low-tech jobs. Case 2, by contrast, implies a positive effect of the minimum wage on both low-skill unemployment and the degree of over-education.

An increase in H/L produces a positive effect on skill mismatch, while the estimates for high- and low-skill unemployment are not statistically significant. This again contradicts the implications of case 2. The predictions of case 1, by contrast, are consistent with the findings for the degree of over-education (positive effect predicted) and unemployment (zero effect on u_L, indeterminate effect on u_H).

We now discuss the panel results. We used both fixed and random effects estimators. The Hausman test rejected the consistency of the random effects estimator in all cases and we report only the fixed effects results.

The panel regressions differ from the time series results in some respects. The coefficients on the minimum wage are negative and are now statistically significant in all three equations. The estimates are also generally larger in absolute value. For example, using estimates from column (4) in table 3, a one percent increase in the state-level minimum wage is predicted to reduce high-skill unemployment by 0.011 percent points, other factors kept constant. It would be unrealistic to assume that the set of included controls is sufficient to give these estimates a causal interpretation.[27] However, the regression results suggest that the monopsonistic features of the class of models presented in section 2 may be empirically relevant.[28] Moreover, to our knowledge no previous studies have suggested a negative relationship between the over-education rate and the minimum wage. According to our findings, such a relationship has both theoretical and empirical support.

The coefficient on the composition of the labor supply (H/L) remains positive and significant for the over-education rate. The estimates for the unemployment rates are now negative but very small in absolute value and statistically insignificant in the case of low-skill unemployment. The sign reversal compared to the time series regressions may be indicative of one of the main weaknesses of using the panel data approach. Arguably, it may be reasonable to take the composition of the labor force as exogenous for the US economy as a whole, but the exogeneity assumption becomes questionable at the state level. The composition of the labor force therefore becomes endogenous, and endogeneity bias may affect all the estimated coefficients.

The panel estimates were robust to a range of specifications. We ran the regressions

[27] We further discuss the possible endogeneity issues in section 4.5 below.

[28] The recent literature finds either no effect or slightly positive effects of the minimum wage on employment (see, among others, Allegretto et al., 2011; Addison et al., 2009).

with and without a separate time trend for each state and while the state-specific trends improve the fit, the changes in the estimated coefficients are small. We also experimented with specifications that included a full set of year dummies (available upon request). The problem with this specification is that the minimum wage effects can be identified only from the small number of observations where state minimum wages exceed the federal minimum (Burkhauser et al., 2000). Not surprisingly, these specifications showed insignificant (while still negative) effects of the minimum wage on both unemployment rates. The coefficient estimate in the over-education rate regression was still negative and significant.

Overall, the results of both the time series and panel regressions reject the case-2 predictions and are largely consistent with case 1.

Table 3: Reduced Form Regression for High-skill Unemployment: 1979.1–2002.4

	Time Series Regressions		State Panel Regressions		
	OLS	GLS-AR(1)	FE	FE+State Trends	
	(1)	(2)	(3)	(4)	(5)
Time Trend	-0.001*	-0.000	-0.001***	-0.001***	-0.001***
	[0.001]	[0.001]	[0.000]	[0.000]	[0.000]
$\ln \underline{w}$	-0.004	0.009	-0.009***	-0.011***	-0.011***
	[0.010]	[0.011]	[0.002]	[0.003]	[0.003]
$\ln \frac{H}{L}$	0.015	0.006	-0.007***	-0.005***	
	[0.022]	[0.011]	[0.002]	[0.002]	
Constant	0.064***	0.034**	0.058***	0.062***	0.064***
	[0.014]	[0.017]	[0.003]	[0.003]	[0.003]
Obs	96	96	4,896	4,896	4,896
R-squared	0.342	0.606	0.150	0.187	0.186
DW	0.130	1.636			

Notes: Dependent variable is the unemployment rate for high-skill workers (0–1 range). Regression (2) assumes the error term follows an AR(1) process. All regressions include quarter dummies. Panel regressions include 51 state fixed effects. Regressions (4)–(5) include state-specific linear time trends. Standard errors in brackets. *** significant at 1% level; ** significant at 5% level; * significant at 10% level.

Table 4: Reduced Form Regression for Low-skill Unemployment: 1979.1–2002.4

	Time Series Regressions		State Panel Regressions		
	OLS	GLS-AR(1)	FE	FE+State Trends	
	(1)	(2)	(3)	(4)	(5)
Time Trend	-0.003*	-0.001	-0.001***	-0.001***	-0.001***
	[0.002]	[0.001]	[0.000]	[0.000]	[0.000]
$\ln \underline{w}$	-0.017	-0.015	-0.024***	-0.030***	-0.029***
	[0.021]	[0.022]	[0.005]	[0.005]	[0.005]
$\ln \frac{H}{L}$	0.029	0.033	-0.012***	-0.004	
	[0.047]	[0.022]	[0.003]	[0.003]	
Constant	0.154***	0.124***	0.133***	0.143***	0.145***
	[0.030]	[0.035]	[0.005]	[0.005]	[0.005]
Obs	96	96	4,896	4,896	4,896
R-squared	0.412	0.774	0.187	0.247	0.247
DW	0.112	1.120			

Notes: Dependent variable is the unemployment rate for low-skill workers (0–1 range). Regression (2) assumes the error term follows an AR(1) process. All regressions include quarter dummies. Panel regressions include 51 state fixed effects. Regressions (4)–(5) include state-specific linear time trends. Standard errors in brackets. *** significant at 1% level; ** significant at 5% level; * significant at 10% level.

Table 5: Reduced Form Regression for Over-education Rate: 1979.1–2002.4

	Time Series Regressions			State Panel Regressions				
	OLS		GLS-AR(1)	FE		FE+State Trends		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Time Trend	-0.003***	-0.003***	-0.003***	-0.001***	-0.001***	-0.001**	-0.001**	0.004***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
$\ln \underline{w}$	-0.016***	-0.017***	-0.017**	-0.022***	-0.022***	-0.015***	-0.015***	-0.019***
	[0.005]	[0.005]	[0.008]	[0.003]	[0.003]	[0.003]	[0.003]	[0.004]
$\ln \frac{H}{L}$	0.168***	0.169***	0.149***	0.110***	0.110***	0.102***	0.102***	
	[0.012]	[0.011]	[0.014]	[0.002]	[0.002]	[0.002]	[0.002]	
u_L (HP-dev)		0.209***	0.128*		0.094***		0.092***	0.080***
		[0.057]	[0.074]		[0.014]		[0.014]	[0.016]
Constant	0.287***	0.287***	0.276***	0.265***	0.265***	0.254***	0.253***	0.195***
	[0.008]	[0.007]	[0.010]	[0.003]	[0.003]	[0.003]	[0.003]	[0.004]
Obs	96	96	96	4,896	4,896	4,896	4,896	4,896
R-squared	0.956	0.962	0.913	0.614	0.617	0.649	0.652	0.508
DW	1.011	1.246	2.142					

Notes: Dependent variable is the over-education rate (range 0–1). Regression (3) assumes the error term follows an AR(1) process. All regressions include quarter dummies. Panel regressions include 51 state fixed effects. Regressions (6)–(8) include state-specific linear time trends. Standard errors in brackets. *** significant at 1% level; ** significant at 5% level; * significant at 10% level.

4.3 The high-tech wage premium w_H/w_L

The wage premium in high-tech jobs will be affected by changes in the minimum wage. Our simplified model in section 3 has only two job categories, low- and high-tech. A direct application of the model implies that $w_L = \underline{w}$, and —assuming profit maximization under constant returns to scale— an increase in the minimum wage therefore leads to a decline in w_H, that is, $d\log(w_H/w_L)/d\log\underline{w} < -1$. With a range of different jobs and different skills, however, a change in the minimum wage will generate a cascade of changes in the wage distribution. One would still expect the average wage for the subset of low-tech jobs to move in the same direction as the minimum wage, and the elasticity $d\log(w_H/w_L)/d\log\underline{w}$ should be negative. Its value, however, will depend on the distribution of skills and jobs and on the chosen delineation of the subsets of high- and low-tech jobs.

We estimated a reduced form relation with the high-tech wage premium as the dependent variable and the minimum wage, the composition of the labor supply and a time trend as regressors:

$$\log\frac{w_{H,t}}{w_{L,t}} = \beta_0 + \beta_1 t + \beta_2 \log\underline{w} + \beta_3 \log\frac{H}{L} \tag{45}$$

The results are in Table 6. Column 1 has the baseline time series specification. Column 2 adds a cyclical correction (the deviation of the unemployment rate from its trend) since the adjustment speeds of both wages and employment in response to shocks may be different for high-and low-tech jobs. The DW statistic rejects the null of no autocorrelation, so in Column 3 we offer GLS estimates that assume an AR(1) process for the error term.

The three time series specifications yield similar results[29]. We get a negative (although statistically insignificant in the GLS-AR(1) specification) coefficient on the

[29] We also estimated the same set of specifications on a composition-adjusted relative wage dependent variable. These results are available upon request and very close to those of the unadjusted variable.

minimum wage, and the negative effect of an increase in the relative supply of high-skill labor is also what one would expect. The positive time trend, finally, is consistent with skill-biased technical change and/or power-biased technical change.[30]

The panel regressions in columns (4)–(7) differ in whether they include cyclical corrections and state-specific time trends. The effects of these variations in specification are very minor. We also estimated the same specification omitting the relative supply variable (column (8) in the table). The minimum wage coefficient remains negative and significant.

Table 6: Reduced Form for the Log Hi/Low-tech Wage Gap: 1979.1–2002.4

	Time Series Regressions			State Panel Regressions				
	OLS		GLS-AR(1)	FE		FE+State Trends		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Time Trend	0.012***	0.012***	0.009***	0.005***	0.005***	0.004***	0.004***	0.003***
	[0.001]	[0.002]	[0.002]	[0.000]	[0.000]	[0.001]	[0.001]	[0.001]
$\ln \underline{w}$	-0.040*	-0.041*	-0.024	-0.024**	-0.024**	-0.030***	-0.029***	-0.028**
	[0.021]	[0.021]	[0.036]	[0.011]	[0.011]	[0.011]	[0.011]	[0.011]
$\ln \frac{H}{L}$	-0.216***	-0.216***	-0.107*	-0.029***	-0.029***	-0.035***	-0.035***	
	[0.045]	[0.046]	[0.056]	[0.008]	[0.008]	[0.008]	[0.008]	
u_L (HP-dev)		0.072	0.128		-0.038		-0.039	-0.035
		[0.234]	[0.300]		[0.052]		[0.050]	[0.050]
Constant	0.228***	0.228***	0.274***	0.306***	0.306***	0.308***	0.308***	0.328***
	[0.030]	[0.030]	[0.046]	[0.012]	[0.012]	[0.012]	[0.012]	[0.011]
Obs	96	96	96	4,896	4,896	4,896	4,896	4,896
R-squared	0.871	0.872	0.710	0.153	0.153	0.229	0.229	0.226
DW	0.871	0.869	2.336					

Notes: Dependent variable is $\ln\left(\frac{w_H}{w_L}\right)$. Regression (3) assumes the error term follows an AR(1) process. All regressions include quarter dummies. Panel regressions include 51 state fixed effects. Regressions (6)–(8) include state-specific linear time trends. Standard errors in brackets. *** significant at 1% level; ** significant at 5% level; * significant at 10% level.

4.4 Spurious correlation?

The correlation between the minimum wage and wage inequality has been noted in previous studies. It has also been suggested, however, that this correlation may be spurious and that shifts in the demand for skills, rather than autonomous changes in non-market factors, have been central to the movements in relative wages and employment.

Is there any direct evidence of spurious correlation? Autor et al. (2008) point to the existence of a time series correlation not just between the minimum wage and lower tail inequality (the 50/10 ratio) but also between the minimum wage and upper tail inequality (90/50). The latter correlation, they argue, is "unlikely to provide causal estimates of minimum wage impacts" (p.311). Instead, this correlation suggests that causal influence of minimum wages in these regressions should be discounted. We do not find this conclusion persuasive.

Our model, first, implies that changes in the minimum wage has ripple effects on over-education and wages throughout the wage distribution. We would expect the

[30] The case for skill-biased technological change has been challenged by, among others, (Howell, 1999; Card and DiNardo, 2002). Skott and Guy (2007) and Guy and Skott (2008) suggest that there is stronger evidence for "power-biased" technological change and that, like skill bias, a power bias can increase both wage and employment inequality. Power-biased technical change produces shifts in the no-shirking conditions, and the positive trend could reflect both skill-biased and power-biased technical change.

effects to be stronger at the lower tail than at the upper tail of the distribution, but there will be some effect at the upper tail too. In line with this expectation, the results reported by Autor et al. (2008) show much stronger effects at the lower tail than at the upper tail: the coefficients on the minimum wage are -.23 and -.10, respectively. Had the coefficients been reversed —with the stronger effect on upper tail inequality— then it could have been seen as evidence of spurious correlation, but it is not obvious that a coefficient of -0.10 is too high to be plausible.

One should still be cautious about causal attribution, in particular if there are reasons to suspect that changes in the minimum wage may be determined endogenously by labor market conditions. It could be argued that the decline in the minimum wage reflects the decrease in the demand for low-skill workers and that the slide in the real value of the minimum wage was necessary to prevent rising low-skill unemployment. Our model questions this premise: low-skill employment may suffer as a result of a falling minimum wage.

Lastly, changes in the minimum wage are related to political pressures and general ideological trends. These trends have generated a range of non-market changes, from labor market legislation and declining unionization to changes in fairness norms and the deregulation of the financial industry. The estimated effect of the minimum wage may be capturing the influence of these other non-market factors. This potential problem of interpretation, however, does not imply that non-market changes merely reflect market fundamentals.

5 Conclusion

The theoretical model in this paper is highly stylized and clearly tells —at best— a small part of the story behind increasing inequality. Several results, however, stand out and may play a role in a more elaborate account of the observed changes.

We have shown that if firms prefer to fill low-tech jobs with low-skill workers rather than with over-educated high-skill workers then ‘aggregate monopsonistic elements’ arise naturally in a model with mismatch. These monopsonistic elements imply that a fall in the minimum wage can have adverse effects on aggregate employment as well as on the degree of mismatch and the rate of *under*employment of high-skill workers. A fall in the minimum wage can produce a rise in both within and between group inequality and low-skill workers may suffer a double blow of declining employment and wages.

The evidence reported in section 4 suggest that these theoretical results may be empirically relevant. There is strong evidence of mismatch in the labor market, and the degree of mismatch has been increasing, especially in the 1970s and 1980s. Moreover, the monopsonistic implications of the theoretical model are supported by US data for 1979–2002. Our regressions suggest that the fall in the minimum wage led to a deterioration of the employment and relative wage of low-skill workers and an increase in the underemployment of high-skill workers.

A The Minimum Wage in a General Setting

Using the general setting in section 2.1, the introduction of a binding minimum wage means that the wage equations (8)–(10) are replaced by the following equations:

$$w_H = \phi^{HH}\left(\frac{N_{HH}}{H}, \frac{N_{HL}}{H}, w_L\right); \quad \phi_1^{HH} > 0, \phi_2^{HH} \geq 0, \phi_3^{HH} \geq 0 \tag{46}$$

$$w_L = \underline{w} \tag{47}$$

$$w_L = \phi^{LL}\left(\frac{N_{LL}}{L}, w_H\right); \qquad \phi_1^{LL} > 0, \phi_2^{LL} \geq 0 \tag{48}$$

In accordance with the Bewley argument, high-skill workers are rationed in low-tech jobs, and their wage equation (9) has been dropped; the equation for the binding minimum wage, equation (50), takes its place. The general form of the wage equations for high-tech jobs and low-skill workers, by contrast, is unchanged.

Equations (49)–(51) —which incorporate the conditions $w_{LL} = w_{HL} = w_L$ and $w_{HH} = w_H$— can be used to examine the effects of a rise in the minimum wage $\underline{w}$. Using (31) and (51), we have

$$\frac{N_{LL}}{L} = \psi(\underline{w}); \quad \psi' > 0 \tag{49}$$

Equation (52) shows that N_{LL} will increase following a rise in the minimum wage, that is, low-skill workers will benefit both in terms of wages and employment.

Substituting (31)–(32) and (52) into (49), we get the following reduced form equation:

$$\zeta(\underline{w}) = \phi^{HH}\left(\eta(\underline{w})\left[\frac{L}{H}\psi(\underline{w}) + \frac{N_{HL}}{H}\right], \frac{N_{HL}}{H}, \underline{w}\right) \tag{50}$$

Using the implicit function theorem, this equation defines N_{HL} as a decreasing function of $\underline{w}$:

$$\frac{N_{HL}}{H} = \chi\left(\underline{w}, \frac{L}{H}\right); \quad \chi_1 < 0, \chi_2 < 0 \tag{51}$$

From (32), (52) and (54) it follows that

$$\begin{aligned}
\frac{\partial N_H}{\partial \underline{w}} &= H\frac{\partial (N_H/H)}{\partial \underline{w}} \\
&= \eta'(\underline{w})\left[H\chi\left(\underline{w}, \frac{L}{H}\right) + L\psi(\underline{w})\right] \\
&\quad + \eta(\underline{w})\left[H\chi_1\left(\underline{w}, \frac{L}{H}\right) + L\psi'(\underline{w})\right]
\end{aligned} \tag{52}$$

The effects of a rise in the minimum wage on the number of low-tech jobs and total employment can now be written

$$\begin{aligned}
\frac{\partial N_L}{\partial \underline{w}} &= H\frac{\partial N_{HL}}{\partial \underline{w}} + L\frac{\partial N_{LL}}{\partial \underline{w}} \\
&= H\chi_1\left(\underline{w}, \frac{L}{H}\right) + L\psi'(\underline{w}) && (53) \\
\frac{\partial N}{\partial \underline{w}} &= \frac{\partial N_H}{\partial \underline{w}} + \frac{\partial N_L}{\partial \underline{w}} \\
&= \eta'(\underline{w})\left[H\chi\left(\underline{w}, \frac{L}{H}\right) + L\psi(\underline{w})\right] + \\
&\quad [1+\eta(\underline{w})]\left[H\chi_1\left(\underline{w}, \frac{L}{H}\right) + L\psi'(\underline{w})\right] && (54)
\end{aligned}$$

The effect of a rise in $\underline{w}$ on N_H is ambiguous. Not surprisingly, it may be negative but a positive effect can be obtained if N_{LL} is elastic and an increase in the minimum wage generates a large decrease in N_{HL}.

It is readily seen that

$$\frac{\partial N_L}{\partial \underline{w}} > 0 \Rightarrow \frac{\partial N}{\partial \underline{w}} > 0 \Rightarrow \frac{\partial N_H}{\partial \underline{w}} > 0 \tag{55}$$

Thus, an increase in N_H is a necessary condition for expansionary effects on total employment or – an even stronger result – on low-tech employment.

As a simple analytical example of strong monopsonistic results, let $H = L = 1$ (for simplicity), $\eta' = 0$ (a Leontief production function), $\phi_3^{HH} = 0, \phi_1^{HH} = \phi_2^{HH} \rightarrow \infty$ (high-tech wages are independent of the minimum wage and highly sensitive to movements in the aggregate high-skill employment rate $(N_H + N_{HL})/H$. With these assumptions, the expression for the change in low-tech jobs can be written

$$\frac{\partial N_L}{\partial \underline{w}} = \frac{1}{1+\eta(\underline{w})}\psi'(\underline{w}) > 0 \tag{56}$$

B Basic processing of May/ORG CPS and DOT Data

Data on skill requirements comes from the Dictionary of Occupational Titles 4th Edition (1977) and revised 4th Edition (1991). We use the dataset compiled by Levy and Murnane (1992) that contains weighted averages of three GED scores (language, reasoning, and math) by occupation and sex using both the 1970 and 1980 3-digit occupational classifications. Only the highest GED is binding so we drop the other two. Scores for years other than 1977/91 are linearly extrapolated. The 1970 and 1980 Census occupational classifications are available in the CPS only during the period 1973–2002. Thus, we use the May CPS for 1973–78 and the merged outgoing rotation groups for 1979–2002. The general inclusion criteria are: age in the range 18–65, to have worked in the past, and potential experience between 1 and 40 years.

Calculations that involve earnings are done using the standard earnings weight multiplied by usual weekly hours. Our wage variable is the log of real hourly earning

Table B.1: Descriptive Stats: 1979.1–2002.4

Variable	Time Series Mean	Time Series sd	State Panel Mean	State Panel sd
u_H	0.038	0.009	0.037	0.016
u_L	0.082	0.020	0.079	0.034
Ω	0.366	0.047	0.371	0.081
$\ln(\overline{w}_H/\overline{w}_L)$	0.415	0.041	0.378	0.094
$\ln(N_H/N_L)$	-0.434	0.139	-0.450	0.246
$\ln(\underline{w})$	0.791	0.102	0.808	0.104
$\ln(H/L)$	0.058	0.234	0.040	0.353
u_L (HP dev)	0.000	0.009	0.000	0.019
Obs	96		4896	
# of States			51	

in 1979 dollars (deflated using the CPI-U-RS). Hourly earnings are weekly earnings divided by usual weekly hours with the exception of cases in which a separate higher hourly wage is reported. After 1994 individuals are allowed to answer that their hours vary. We use a simple regression imputation approach to assign hours to those individuals. No allocated earnings are utilized, however. During the period 1989–93 the allocation flags fail to identify most imputed earnings. Following Lemieux (2006), we use the unedited earnings variable to identify and drop unflagged allocated earnings. Topcoded earnings are winsorized using a 1.4 factor.

Table B.2: A Comparison of Different Skill Requirement Measures: 1983–2002

Occupation		Employment Share		GED		DCP		STS		Occupational Outlook Handbook Description	
Code	Description	1983	2002	1983	2002	1983	2002	1983	2002	1983	2002
22	Managers and administrators, n.e.c.	4.6%	5.3%	4.30	4.26	5.24	5.24	1.44	1.40	Most managerial and administrative positions require a college education.	For first-line administrative service managers, many employers prefer an associate's degree in business or management, although a high school diploma may suffice
243	Supervisors and Proprietors, Sales Occupations	2.2%	3.1%	4.31	4.26	5.25	5.25	1.43	1.39	Traditionally, capable sales workers without a college degree could advance to management positions. However, a college education is becoming increasingly important for advancement.	Most supervisors hold associate or bachelor's degrees.
804	Truck drivers	2.3%	2.3%	2.95	2.93	1.02	1.02	1.17	1.17	Most training authorities and employers recommend high school driving training courses.	All drivers must able to read and speak English well enough to read road signs, prepare reports, and communicate with law enforcement officers and the public. Many prefer to hire high school graduates.
156	Teachers, elementary school	1.8%	2.1%	4.98	4.98	3.42	5.91	1.01	1.01	In all States and the D.C. prospective kindergarden or elementary school teachers must have a bachelor's degree from an institution with an approved teacher education program.	At least a bachelors degree plus approaved teacher training program
95	Registered nurses	1.7%	2.1%	4.91	4.90	1.41	1.41	5.58	5.63	There are 3 types of nurse training program: 2 year associate degree programs, 3 year diploma programs, and 4 or 5 year bachelor's degree programs.	Three educational paths to licensed nursing: associate degree in nursing (community college, 2-3 years), bachelor of science degree in nursing (college/university, 4-5 years), and diploma (hospitals, 2-3 years).
313	Secretaries	4.6%	1.9%	4.00	4.00	1.09	1.09	4.08	1.65	A high school diploma generally is required for a job as a secretary or stenographer.	High school graduates who have basic office skills may qualify for entry-level secretarial positions.
276	Cashiers	1.9%	1.8%	3.12	3.06	1.05	1.05	5.42	5.44	Employers prefer beginning cashiers with high school diplomas.	Requires only high school diploma
447	Nursing aides, orderlies, and attendants	1.4%	1.8%	3.26	3.25	1.08	1.09	1.60	1.63	While high school graduates are preferred, employers do not always insist on a diploma.	In many cases, neither a high school diploma nor previous work experience is necessary for a job as a nursing, psychiatric, or home health aide.
436	Cooks	1.4%	1.6%	3.30	2.66	1.33	1.33	4.74	4.74	Even though a high school diploma is not required for beginning jobs, it is recommended for those planning a career as a cook or chef.	High School diploma is advisable.
453	Janitors and cleaners	1.8%	1.5%	2.29	2.22	1.24	1.24	3.29	3.24	Workers who have limited skills or little education can often find jobs in this field.	No special education is required
64	Computer systems analysts and scientists	0.3%	1.4%	5.23	4.97	3.26	4.49	2.80	3.03	College graduates generally are sought for these jobs, and, for some of the more complex jobs, persons with graduate degrees are prefered	A bachelors degree is a pre-requisite for many jobs; however, some jobs may require only a 2 year degree
23	Accountants and auditors	1.1%	1.3%	4.76	4.72	4.84	4.62	5.47	5.33	Most public accounting and business firms require applicants for accountant and internal auditor positions to have at least a bachelor's degree in accounting or closely related field.	Require at least a bachelor's degree in accounting or related field.

Notes: Sources are U.S. Department of Labor (1977, 1991) and U.S. Bureau of Labor Statistics (1982, 2002). Employment shares are from the CPS-MORG. General Education Development (GED); Direction, Control, Planning (DCP); and Set Limits, Tolerances, or Standards (STS) are all DOT-based measures (1–6 scale) of the complexity of non-manual tasks required in each occupation. The Handbook descriptions are verbatim quotes from the 'Training, Other Qualifications, and Advancement' section for each of the occupations.

Table B.2: A Comparison of Different Skill Requirement Measures: 1983–2002 (continued)

Occupation		Employment Share		GED		DCP		STS		Occupational Outlook Handbook Description	
Code	Description	1983	2002	1983	2002	1983	2002	1983	2002	1983	2002
157	Teachers, secondary school	1.6%	1.2%	4.97	4.97	5.63	5.98	1.06	1.01	In all States and the D.C. prospective teachers need a bachelor's degree from an approved teacher training program with a prescribed number of credits in the subject they plan to teach.	At least a bachelors degree plus approaved teacher training program
259	Sales representatives, mining, manufacturing, and wholesale	1.3%	1.2%	3.87	3.79	1.18	1.18	1.11	1.08	A college degree is increasingly desirable for a job as a manufacturer's salesworker.	A Bachelors degree increasingly is required
337	Bookkeepers, accounting, and auditing clerks	2.0%	1.1%	3.99	3.99	1.20	1.20	5.80	5.71	High school graduates who have taken business arithmetic, bookkeeping, and principles of accounting meet the minimum requirement for most bookkeeping jobs.	In many cases a high school diploma is not necessary.
567	Carpenters	0.9%	1.0%	3.92	3.91	1.18	1.18	5.86	5.79	A high school or vocational school education is desirable, including courses in carpentry, shop, mechanical drawing, and general mathematics.	A high school education is desireable.
16	Managers, food serving and lodging establishments	0.0%	1.0%	4.00	4.23	6.00	6.00	1.00	1.00	Employers are increasingly emphasizing college education. A bachelor's degree in hotel and restaurant administration provides particularly strong preparation for a career in hotel management.	Post-secondary training in hotel or restaurant management is preferred for most positions, although a college liberal arts degree may be sufficient.
435	Waiters and waitresses	1.4%	1.0%	2.91	2.88	1.13	1.13	1.07	1.06	Most employers prefer to hire applicants who have at least 2 or 3 years of high school.	There are no specific educational requirements.
889	Laborers, except construction	1.1%	1.0%	2.30	2.31	1.02	1.02	2.17	2.21	Little formal training is needed	Basic literacy is a must if the worker is to read and understand warning signs and intructions.
376	Investigators and adjusters, except insurance	0.4%	1.0%	3.94	3.85	1.36	1.36	2.60	2.60	Although a growing number of insurance companies prefer college graduates, many hire those without college training, particularly if they have specialized experience.	Most companies prefer to hire college graduates
274	Sales workers, other commodities	1.2%	0.9%	3.41	3.00	1.14	1.14	1.27	1.26	Employers usually seek hgih school graduates and have experience sales clerks train them on the job.	A Bachelors degree increasingly is required
389	Administrative support occupations, n.e.c.	0.5%	0.9%	3.46	3.44	1.24	1.24	4.53	3.84	Employers prefer high school graduates for clerical jobs.	Employers usually require high school diploma.
628	Supervisors, production occupations	1.4%	0.9%	4.05	4.03	5.10	5.12	3.09	2.83	Completion of high school often is the minimum occupational requirement, and 1 or 2 years of college or technical school can be very helpful to workers who want to become supervisors.	Many employers require post-secondary training, an associate's or even bachelor's degree
785	Assemblers	1.0%	0.8%	2.52	2.42	1.01	1.01	4.50	4.39	A high school diploma is helpful but usually not required.	A high school diploma is preferred for most positions
319	Receptionists	0.6%	0.8%	3.12	3.13	1.16	1.20	1.32	1.24	Employers usually require that receptionists have a high school diploma.	A high school diploma or its equivalent is the most common educational requirement

Notes: Sources are U.S. Department of Labor (1977, 1991) and U.S. Bureau of Labor Statistics (1982, 2002). Employment shares are from the CPS-MORG. General Education Development (GED); Direction, Control, Planning (DCP); and Set Limits, Tolerances, or Standards (STS) are all DOT-based measures (1–6 scale) of the complexity of non-manual tasks required in each occupation. The Handbook descriptions are verbatim quotes from the 'Training, Other Qualifications, and Advancement' section for each of the occupations.

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