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The Minimum Wage Spike in the Search Economy with Wage-Posting

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Abstract

Empirical wage and wage offer distributions exhibit substantial clustering in economies with a mandated minimum wage, the phenomenon knows as the minimum wage spike, as well as wage dispersion. Existing search-theoretic literature does not replicate both of the empirical phenomena simultaneously. This paper attempts to reconcile the two under assumptions of wage-posting, urn-ball matching and firm productive heterogeneity. A non-degenerate minimum wage spike and wage dispersion are obtained when firm wage determination embodies both incentives for collusion at the minimum wage and competition at the same time, making the spike and the dispersion the outcomes of partially collusive equilibrium. Besides this main result, the paper also shows that a higher minimum wage may reduce unemployment.

Journal of Economic Literature Classification: J30, J64

Keywords:wage-posting, minimum wage, minimum wage spike, wage dispersion, unemployment

1 Motivation and Related Literature

Minimum Wage Spike and Wage Distribution

This paper analyzes the coexistence of two interesting empirical phenomena, the minimum wage spike and the wage dispersion, within the search theoretic framework. It has been long noticed that empirical wage distributions have spikes alongside a continuous tale in economies with mandated minimum wages, as summarized by Brown (1999):

> "Among those who are employed, the distribution of ln(wage) tends to look bell-shaped with occasional spikes at round-dollar amounts. Often there is another spike, at the minimum wage, even when the minimum is not a round-dollar amount. Spikes at the minimum wage are stronger when the minimum wage is more binding; e.g. in wage distributions for teenagers rather than for all workers, and in years when the minimum wage has been raised rather than after several years of a constant nominal and eroding real minimum wage."

According to the Department of Labor, about 2-2.5% of the hourly workforce is paid a minimum wage or less. The distributional clustering is stronger in the distributions of wage offers[1]. This clustering, often referred to as the minimum wage spike, is more pronounced in the markets directly affected by minimum wages such as the markets for teenagers or high-school dropouts, retail and food industry workers, and it is persistent over time (Figure 1).

Along with the spike, wage distributions are characterized by wage dispersion. The existence of the price and the wage dispersion, once a puzzle, has been discussed by many economists. Stigler (1961), was perhaps among the first who attributed dispersion in prices to the existence of search frictions (e.g., search cost) in the process of non-sequential search. A decade later Diamond (1971) pointed out that dispersion disappears in the price-posting environment with costly sequential search. While this discovery was important, it ushered the literature in the direction of unraveling the Diamond paradox (Woodbury and Davidson, 2002).

Current labor search literature encounters a number of modeling approaches that generate wage dispersion. For example, Mortensen (2003),

[1] For example, a job vacancy survey of St.Louis metropolitan area in October 2007(Survey of Job Openings in St.Louis Metropolitan Area, October 2007.) showed that in the market for entry level positions about 60% of vacancies offer wages of $8 or less (minimum wage is $5.15). While roughly 65% of all available vacancies in St.Louis at the time were entry level positions, we observe that 40% of all entry level positions are practically minimum wage jobs.

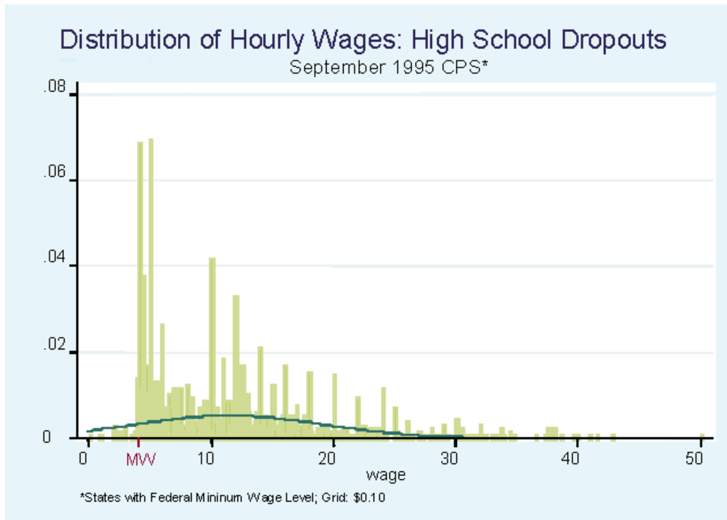

Figure 1: Wage Histogram for High-School Dropouts

whose model is based on Burdett and Mortensen (1998), shows that pure wage dispersion can be obtained in the search setting with multiple wage offers, following Stigler's tradition. In the Mortensen's model firms choose wage offers by maximizing expected profits, which balances out a probability of offer acceptance with a higher wage.

In the original Burdett and Mortensen(1998) model wage dispersion is obtained thanks to the assumption of on-the-job search: wage offers arrive not only to the unemployed, but also to the employed workers. A similar assumption was later adopted by Postel-Vinay & Robin (2000a, 2000b) and some others. In these models offers arrive to the employed workers, which leads to a Bertrand-style competition between a worker's current and prospective employers. This allows workers to move up the wage ladder leading to wage dispersion.

Another modeling approach that was successful in replicating wage dispersion is the directed search (Shi and co-authors, various papers). Here the ability of workers to observe all available wage offers and allowance for mixed strategy job applications triggers competition among vacancies that post wages simultaneously. The allowance for the mixed strategy application can be also related to Stigler's non-sequential search.

There are a number of wage-posting models that combine listed approaches to generating wage dispersion. For example, Delacroix and Shi(2003) developed a model of directed on-the-job search. Albrecht and Gautier(2005) and Albrecht, Gautier, and Vroman(2006) combines the directed search assumption with simultaneous multiple applications.

Overall, the mentioned search models replicate wage dispersion by directly or indirectly adhering to the original Stiglerian idea of competition for workers that takes root in the non-sequentiality of the search process, thus breaking the tendency for monopsonistic equilibrium described by Diamond. The various assumptions adopted by the modelers makes the dynamic market more competitive, either by increasing information available to workers, as in the case with directed search, or by increasing the options available to workers, as in the case of on-the-job search or the search with multiple offers. On the opposite end, when these competitive triggers are absent a single Diamond-style wage equilibrium emerges.

While the puzzle of wage dispersion was successfully solved, its coexistence with the minimum wage spike still demands an explanation. Among authors working within search framework, Manning (2003) and Flinn (2003) were able to replicate the minimum wage spike. Manning, within the theory of dynamic monopsony and wage-posting, argues that the minimum wage spike can appear if the labor supply is a continuous function of wage, and firms are heterogeneous in productivity. He, however, also warns that the spike should dissipate over time, "...because it would ... pay employers to deviate by paying an infinitesimally higher wage"(Manning, 2003a, p.327). Flinn (2003) was also able to obtain the minimum wage spike assuming that wages are a product of Nash-bargaining, where the minimum wage serves as a binding constraint.

This paper develops a model in the wage-posting tradition with heterogenous firms and competitive elements to allow for wage dispersion. It also introduces an element that restricts competition and allows to obtain a nondegenerate minimum wage spike. Previous research was unable to replicate the two phenomena simultaneously under the assumptions of wage-posting.

Minimum Wage and Low-Wage Markets: Stylized Facts

The minimum wage spike and the wage dispersion are salient characteristics of the low-wage markets with the mandated minimum wage. Wage clustering, or the spike, at the minimum is shown to be responsive to changes in the minimum wage levels. When the minimum increases, the fraction of observations at the minimum rises. As the real minimum wage erodes, this fraction declines. As can be seen from Figure 2, the percentage of minimum

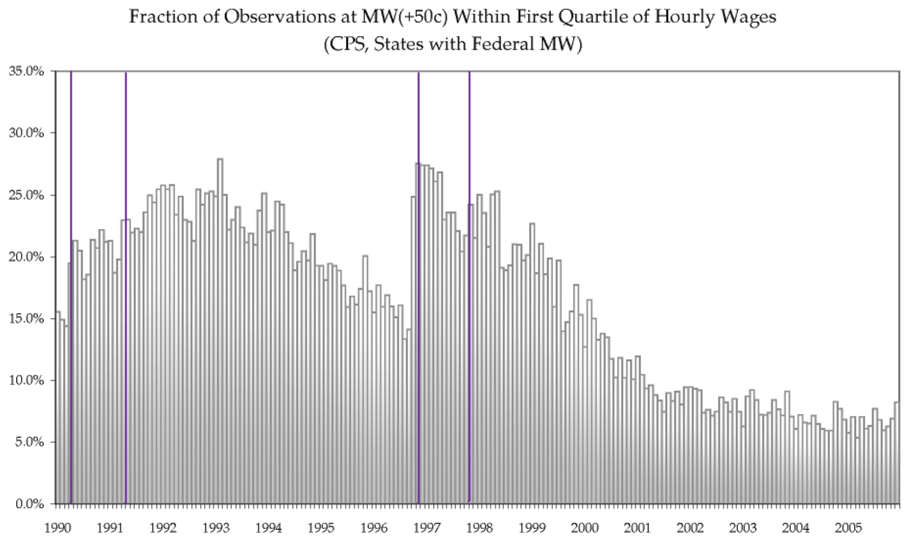

Figure 2: Fractions of Minimum Wage Observations

wage observations within the first quartile of hourly wages (in states that follow the federal minimum wage regulation) increases following the hikes of 1990-91 and 1996-97 (labeled as vertical lines).

There is general consensus among empirical labor economists that a higher minimum wage increases wages (Brown, 1999), though often this wage-lifting effect is short-lived. It has been also shown that an introduction of the minimum wage increases wage compression (e.g., Machin, Manning, & Lupin, 2003). Also, it has been widely discussed that the hikes in minimum wages do not significantly reduce employment or increase unemployment: only few studies surveyed by Brown (1999) reported a significant negative impact of a higher minimum wage on adult or total employment. In the 1995 book Card and Krueger (1995) summarized a series of studies where they showed that the minimum wage increases of the 1990's did not reduce employment, and in some cases even increased it. Studies that do find positive and significant elasticities of employment response to minimum wage (e.g., Burkhauser et al., 1996) advise that only the markets for teenagers and youth are mildly affected.

The goal of this paper was to produce a model that would not only replicate the non-eroding minimum wage spike alongside dispersion, but also reflect changes in the size of the spike due to shifts in the minimum. Model simulations show that greater productivity can also reduce the spike. In addition, the model demonstrates that a higher, but non-binding minimum wage can both increase wages and reduce unemployment. Higher wages could also be obtained, but generally at the cost of greater wage compression.

The rest of the paper is organized as follows. The next, second, section outlines the model and describes the behavior of labor market participants. The third section presents a single period search model in the tradition of Mortensen(2003), which performance is then illustrated with a series of numerical simulations. The fourth section presents an intertemporal search model. It further investigates the dynamics of wages and unemployment in economies with a non-binding minimum wage and no entry. The paper ends with a numerical simulation that mirrors the federal minimum wage hikes in the US in 1996-1997 in the specific low-wage market – the market for high-school dropouts.

2 The Model Overview

The Labor Market

The model labor market is represented by M heterogenous firms, indexed by j with a fraction v of them vacant, and N homogenous workers, indexed by i, with a fraction u of them unemployed. Each firm has exactly one vacancy with predetermined productivity y_j. The entry of new firms into the market is restricted, allowing existing firms to earn positive profits when occupied and have positive vacancy values when vacant. Each worker supplies one unit of labor to the market inelastically.

In any period t a fraction s of existing worker-firm matches are exogenously destroyed, firms become vacant and workers exit into the pool of unemployed. An unemployed worker enters the job market and searches for a wage offer that exceeds his reservation wage w_r.

While searching, the worker samples the wage offer distribution in a way similar to a lottery drawing, the process further described in the next section entitled 'Multiple Quotes'. Each period an unemployed worker is able to obtain two wage quotes from two vacant employers[2]. After wage quotes are received, the worker applies to a firm that offers a higher wage. The worker is not allowed to send applications in a mixed-strategy manner to both firms. If the worker receives identical wage quotes, he randomly selects one.

[2]Double sampling is chosen for simplification, but can be generalized.

A vacant firm upon entering the job market is able to observe the exact mix of firms that are currently vacant, i.e. view their productivities and their ranks in the distribution. It also has unemployment statistics available that allows to calculate the expected matching probability. This assumption of 'perfect monitoring' also extends into the environment with collusion, where a fraction of productively heterogenous firms choose to offer the same wages equal to the minimum wage. Since collusion will be self-enforced by market participants through a 'punishment mechanism' , the ability to monitor other firms' wage-posting decisions becomes necessary for collusion to be sustainable.

Multiple Quotes

The assumption of multiple quotes, or multiple sampling of the wage offer distribution, is similar to Mortensen's model with multiple offers (which continues on Stigler's tradition of non-sequential search). Multiple quotes assumption made here is also very similar to the multiple applications assumption described for instance by Gautier and Moraga-Gonzalez(2005), Albrecht et al.(2006). In their case workers send out multiple applications in a random fashion to a set of employers, i.e. they sample the 'urn' of vacancies, with the prospect of receiving one or more offers. Vacant firms that receive more than one application randomly choose a worker whom they make an offer (assuming workers are identical). Workers who receive multiple offers can discriminate in favor of a higher offer, thus generating incentives for the vacancies to compete.

Albrecht et al.(2006) suggest that such a search process closely resembles the search process for Economics Ph.D.'s: job seekers send out multiple applications to job openings and pick the highest offer among potentially multiple offers. The multiple application approach is viable in this case due to the fact that the information about available vacancies is centralized, the marginal cost of an application is low, and the final payoff is high relative to the search cost.

In low-wage markets the information about job openings is highly scattered, and both gathering vacancy information and sending/filling out multiple applications is costly relative to the prospective wage. Thus, assuming that the low-skill workers are restricted to obtaining information on only two vacancies in a single search period and that they fill out a single application seems reasonable. Though the application process is slightly different, the matching mechanism in both 'multiple-offers' market for high-paid workers and 'multiple-quotes' market for the low-paid is similar, at least with respect to the match probability. The two match modeling approaches also share a characteristic known as congestion externality, which is responsible for generating unemployment due to the matching friction that stems from the fact that a vacancy (worker) can receive more than one application (offer).

The assumption of multiple quotes is a rather important to the model. It is the competitive trigger responsible for generating wage dispersion. Firms that face the prospect of workers' sorting among wage offers are willing to trade-off the lower payoff associated with higher wage for the higher probability of matching. The next section defines the matching probabilities that are used by firms in wage determination.

Sampling and Application: Defining Probabilities

The formation of a productive firm-worker match is a three-stage process, with the probability of forming a match determined by the so-called 'urn-ball' matching function. At the first stage each unemployed worker samples the wage offer distribution by being randomly matched with two vacant firms and requests wage quotes[3]. Not all firms are necessarily asked to issue wage quotes since the probability of matching is less than one (as predicted by the urn-ball matching function: Butters 1977, Burdett & Judd 1983; Albrecht et al. 2003 & 2004, Mortensen 2003, and others). As a result, only matched firms have a chance of receiving job applications.

Butters (1977) originally described the urn-ball matching as a process in which sellers contact buyers by dropping off ads in their mailboxes. The buyers mailboxes are the 'balls in the urn', similar to well-known examples in statistical sampling. In my case the urn is the collection of vacancies – the wage offer distribution and the sampling process can be compared to the insurance market, where buyers request insurance premium quotes from a set of insurers.

Each firm can be contacted by any worker. Thus, the number of quotes requested from each firm lies in the range $[0, 2U]$ and is binomially distributed with the average probability of success equal to $\frac{2U}{V}$. If V and U are large, which rules out the possibility of a worker requesting two wage quotes from the same employer, and if the fraction $\frac{2U}{V}$ is stable, the binomial distribution of the number of quotes received by a representative firm can be approximated by the Poisson distribution with the mean $2/\theta$ (where $\theta = \frac{V}{U}$ is labor market tightness[4]).

[3] The restriction on the number of quotes to two is not new to the literature (see Shapiro, 2004), and is chosen for computational simplicity.

[4] To simplify theoretical analysis we assume that U and V are large. For finite U, V

After requesting wage quotes workers begin the application process. They compare values of wage quotes received and apply to a firm offering higher wage. Thus, the firm's probability of filling the vacancy does not only depend on the probability of being sampled defined above, but also on the value of its wage offer. If all heterogenous firms follow an identical rule for wage determination, the probability of receiving an application will depend on the firm's rank $F(w)$ within the overall wage distribution, which should be a one-to-one transformation of the firm productivity distribution. Thus, a single issued quote will lead to the application with probability $F(w)$, the probability that a competing wage quote received by a worker is lower. If it is the case, the worker returns to fill out the job application with probability of one. Thus, a firm that has x wage quotes requested has the probability of at least one worker returning equal to:

$$1 - (1 - F(w))^x .$$

Combining the probability of being sampled (the Poisson random variable) with the probability of receiving an application gives the following expression for the probability of filling a vacancy (similar to Mortensen, 2003:19):

$$\begin{aligned} p_w(\theta, F(w)) &= \sum_{x=0}^{\infty} \left[1 - (1 - F(w))^x\right] \frac{\exp(-\frac{2}{\theta})(\frac{2}{\theta})^x}{x!} = \\ = 1 - \sum_{x=0}^{\infty} [1 - F(w)]^x \frac{\exp(-\frac{2}{\theta})(\frac{2}{\theta})^x}{x!} &= 1 - \exp\left(-\frac{2F(w)}{\theta}\right). \end{aligned} \tag{1}$$

As the expression indicates, the probability of filling a vacancy depends on the labor market tightness θ and on the firm's wage offer w. Simple comparative statics reveal that a tighter labor market reduces the probability of filling a vacancy and a higher wage offer increases such chances, as anticipated:

$$\frac{\partial p_w}{\partial \theta} = -\frac{2F(w)\exp(-\frac{2F(w)}{\theta})}{\theta^2} < 0;$$
$$\frac{\partial p_w}{\partial w} = \frac{2\exp(-\frac{2F(w)}{\theta})}{\theta} > 0.$$

By complementarity, the probability of not filling a vacancy either due to the absence of quote requests or the lack of applicants is:

$$p_0(\theta, F(w)) = \exp\left(-\frac{2F(w)}{\theta}\right). \tag{2}$$

see Albrecht et al. 2004.

Now, consider a market with a cluster of identical wages, such as the minimum wage spike. Suppose that a fraction ρ of vacant firms offers the minimum wage. The number of wage quotes requested is determined in the same way as before, though the probability of receiving an application will be defined slightly differently.

A firm that offers the minimum wage and was sampled by a worker faces the probability equal to ρ that a competitive wage quote is also the minimum wage (true only if the wage cluster is composed of the lowest wages). Since a worker who obtains two identical wage quotes randomly chooses one of them, each firm offering the minimum wage will receive an application from this worker with probability $\rho/2$. The cluster firm with x quotes requested has the following probability of at least one worker returning:

$$1 - \left(1 - \frac{\rho}{2}\right)^x.$$

Combining the probability of being sampled with the probability of receiving an application results in the following probability of filling the cluster (the minimum wage) vacancy:

$$p_m(\theta, \rho) = \sum_{x=0}^{\infty} \left[1 - \left(1 - \frac{\rho}{2}\right)^x\right] \frac{\exp(-\frac{2}{\theta})(\frac{2}{\theta})^x}{x!} == 1 - \exp\left(-\frac{\rho}{\theta}\right). \qquad (3)$$

The Spike Formation

The matching mechanism described in the environment with heterogenous employers will lead to the wage dispersion and by itself will not lead to the formation of the distributional spike for several reasons. First, if firms are heterogenous the possibility of several employers offering exactly the same wage is zero. As Manning (2003, p.327) points out, "... the equilibrium wage distribution can have no mass points because it would then pay employers to deviate by paying an infinitesimally higher wage." The least productive firm will offer a wage slightly above worker's reservation wage and, under perfect monitoring, other more productive firms will offer higher wages. In such a market the introduction of the minimum wage can potentially create an initial wage spike if the minimum is above a worker's reservation wage and if wage adjustment is not instantaneous. Over time the spike will deteriorate and the effect of the minimum wage will reduce to a higher left bound of the wage distribution and smaller support.

In my previous work Shelkova (2008) I provide a microeconomic explanation for the existence of the spike by suggesting that a non-binding minimum wage could become a focal point for tacit collusion by low-wage employers. In the simple dynamic setup homogenous profit-maximizing firms will choose setting wages at the minimum, and this equilibrium will be sustained since deviation is not profitable due to the possible retaliation. As a result, the competition is folded and the market equilibrium outcome resembles a simple monopsony.

In the dynamic model described in this paper, heterogenous firms would not cluster at the minimum wage since the incentives to deviate from the single wage are too strong, driven by the multiple-quotes assumption. However, if firms colluded, at the lowest possible wage such as the minimum wage, the payoffs for all firms were higher. Colluding vacant firms would have an identical probability of hiring, sizably lower than for non-colluders, but earn a higher profit when jobs are filled. In addition, non-colluding firms offering wages above the minimum would also benefit (due to the assumption of perfect monitoring), since their probability of hiring will be positively affected and they will fill the position sooner.

The decision to collude is a classical prisoners' dilemma, in which a cooperative (or as in case with the spike and dispersion – a partially cooperative) equilibrium promises higher payoffs, but the incentives structure forces the players into a non-cooperative, lower payoff for all equilibrium. Thus, a solution to the spike-and-dispersion puzzle could lie in the modification of the firms' payoff functions. Under the right incentives one should be able to obtain an equilibrium in which some firms choose to offer the minimum wage, thus forming the spike, while others will choose to deviate and offer higher wages, contributing to dispersion.

The path to a partially cooperative equilibrium that I choose is different from the traditional super-game approach based on the threat of future retaliation. Future retaliation is a credible threat when punishment is not delayed. It can be argued that in the labor markets transactions are infrequent – the punishment is delayed. Thus, I introduce an additional element into the model that makes cooperation attractive contemporaneously. This element is the additional cost imposed (or self-imposed) on firms that offer wages higher than the minimum, i.e. it is a fine for deviation from the collusive benchmark that enforces cooperation.

This additional cost to deviators is a hurdle to competition that can be created by a group of interested players or it can be a product of the market environment. The latter explanation can be related to the empirical fact that minimum wage vacancies are often more visible than high wage vacancies, inducing higher search costs for high-wage employers to make their vacancies as visible to potential candidates. Firms that offer minimum wages spend less on search since workers may sample their vacancies while not deliberately searching, for example, during lunch or a shopping trip. One can also argue that minimum wage employers can economize on vacancy cost by building a reputation for wage-setting, again making sampling of offers easier for the unemployed. Minimum wage vacancies are also present on the market longer, perhaps, allowing workers to recycle wage information obtained in previous periods.

In order to create an environment for collusion I modify the process of wage determination in the following way. Vacant firms' wage decision is made a binary choice – the choice between the cooperative (minimum wage) wage-setting that is rewarded and the non-cooperative (higher wage) wage-setting that is penalized. If the penalty is high enough to induce firms to set wages at the minimum, even partial collusion pays off to all firms, including the ones who pay the penalty. The combination of greater hiring probability and lower wage offers allows them to earn greater profits.

The choice in which a player has to decide on two actions that can potentially benefit a larger group of market participants is described by Schelling (1973) as a binary choice with externality. In his paper Shelling gives several examples of such situations, starting with the dilemma in which individual hockey players historically refrained from wearing helmets (non-cooperative behavior) since it was perceived as non-manly, even though the practice of wearing helmets could have benefited them individually and the entire league (positive externality). The externality in my case shows in the result when an individual firm decision to pay the minimum wage positively affects payoffs for all others.

Overall, the formation of the minimum wage spike requires two conditions to be met. First, the probability of filling a minimum wage vacancy should be different from zero. This becomes possible if at least two firms choose to set wages equal to the minimum wage. This is achieved with the introduction of the second condition – costly deviation. If the cost is high enough, the first condition becomes automatically satisfied. As a result (under suitable parameter values), even in the environment with heterogenous firms one can observe a subset of firms that offers the same wage, forming the spike. At the same time, wage dispersion can also be observed, representing firms for which it is still optimal to deviate.

3 Single Period Search

Model

To start, consider a basic single period model of job search. In the beginning of the period all firms are vacant and all workers are unemployed. Firms set wages and workers sample wage offers according to the urn-ball matching process and apply to the preferred jobs. It is assumed that workers don't value leisure and supply one unit of labor each period inelastically.

A vacant firm sets its wage in order to maximize the expected profit, which is the product of the probability of filling the vacancy and the difference between productivity and the wage paid:

$$\pi = (y - w)p_w(\theta, F(w)). \tag{4}$$

In order to insure that even the least productive employer has a positive probability of hiring I introduce an additional 'empty' ball in the urn of vacancies. Thus, a worker that happens to draw this 'empty' vacancy along with another valid vacancy in fact has only one wage quote[5]. As a result, the lower bound of the wage offer distribution is defined by the worker's common reservation wage.

If it is assumed that each firm is representative of a productivity type, and the firms within each type generate the same expected profit, then the equilibrium wage distribution has no gaps in its support (to ensure stability of the equilibrium). In this case the upper wage bound for the lower productivity type represents the lower bound for the higher productivity type. For the rest of the paper we will refer to the firm type as 'the firm', since the continuity of the distribution is not of a special interest here.

The actual wage offers (or more accurately, the upper supports for the productivity types), as was mentioned are the trade-off between the higher probability of acceptance associated with a higher wage and the lower probability of acceptance associated with a lower wage, as outlined below:

$$(y_j - w_j)p_w(\theta, F(w_j)) = (y_j - w_{j-1})p_w(\theta, F(w_{j-1})),$$

where y_j and y_{j-1} are the adjacent productivity values (higher j and lower $j-1$), $F(w_j)$ and $F(w_{j-1})$ are the firms' rank in the wage distribution, w_j

[5]The number of 'empty' vacancies can be more than one, in which case some workers will still obtain two wage quotes, some – one wage quote, and others – zero wage quotes. Such an alternative, perhaps, is more realistic than the two-quote assumptions since it is possible that a worker is unable to locate any vacancies in the single search period, but it unnecessarily complicates the analysis.

and w_{j-1} are the optimal wages for respective firms. The optimal wage offer for the firm j:

$$w_j^* = y_j - (y_j - w_{j-1})\frac{p_w(\theta, F(w_{j-1}))}{p_w(\theta, F(w_j))}. \tag{5}$$

The expression shows the dependence of the wage of a more productive firm on the wage of a less productive firm, the mechanism through which the discussed externality reveals itself.

Now, suppose that the firm is placed into making the binary choice: it can post a wage offer equal to the minimum wage, in which case it does not incur any additional vacancy cost[6], or it can post a higher wage offer for which it will have to incur the penalty. Thus, a firm offering the minimum wage m has the expected profit:

$$\pi_m = (y - m)p_m(\theta, \rho). \tag{6}$$

The firm offering a higher wage w has the expected profit of:

$$\pi_w = (y - w)p_w(\theta, F(w)) - C, \tag{7}$$

where C is the penalty for deviation ($\sim$w-vacancy cost).

Under certain parameter values, the productive heterogeneity can ensure that some firms will form a coalition of minimum wage payers, while others will offer higher wages despite the additional vacancy cost, producing the spike and the tale. An individual firm's decision depends on the relative magnitudes of its expected profits π_m and π_w. Thus, an individual firm's wage offer is:

$$w = \begin{cases} m & \text{if } \pi_m \geq \pi_w; \\ w^* & \text{otherwise.} \end{cases}$$

Due to the perfect monitoring assumption, vacant firms are able to predict precisely the fraction of colluders and deviators. Equality of the expected profits defines the boundary productivity that splits all firms into two groups: one that finds it profitable to pay the minimum wage, and another that does not. Thus, the boundary productivity $\hat{y}$ is implicitly given by:

$$(\hat{y} - w)p_w(\theta, F(w)) - C = (\hat{y} - m)p_m(\theta, \rho).$$

As the expression indicates, the spike formation depends on the labor market tightness, the minimum wage level, the productivity distribution, as well as on the value of penalty. The next section explores these relationships.

[6]The normal vacancy cost is normalized to zero.

Table 1: Baseline Parameters (1)

Number of vacancies, V	1,000
Number of unemployed, U	1,000
Productivity distribution	$N(25, 10)$
Minimum wage	5.00
Separation rate	0.10
Market tightness	1.00
W-vacancy cost	1.00

Simulation Results

A simple one-period search model is helpful in learning the basics of forming the labor market coalition such as the minimum wage spike. Consider the following numerical example. A model economy is populated by 1,000 vacant firms with normally distributed productive efficiencies (see Table 1). For computational reasons the associated cdf values are substituted for their simple order ranks[7]. The number of unemployed workers is also set at 1,000, which gives the labor market tightness of one. Unless specifically mentioned, the minimum wage is set at 5. Note that this is not a calibration exercise and the parameter values are chosen arbitrarily.

First, consider the effects of the minimum wage value on the size of the coalition (Fig. 3). The graph demonstrates that a higher minimum wage increases clustering at the minimum, which is observed in empirical data (Figure 2): upon minimum wage hikes the minimum wage spike increases.

While a rise in the minimum wage is an occasional event, the eroding minimum wage is observed continuously. The same graph gives an idea of the speed at which the minimum wage spike decreases as the real minimum wage erodes. It can be seen that the speed of change is not constant, it is slower when the initial coalition is greater and it accelerates as the minimum wage eroded. The graph also shows that the coalition does not disappear even for the very low minimum wage levels, as long as the enforcement costs are relatively high. This can be related to the flat zone in Figure 2 corresponding to 2004-onwards, where the fraction of minimum wage observations stabilizes but does not disappear.

Figure 4 portrays the change in the fraction of minimum wage observations as the w-vacancy costs change. Clearly, the more costly deviation

[7] I see it as a reasonable substitution, since the probability of filling a vacancy will only depend on the firm's overall distributional rank. It does, however, mildly affect the shape of the final wage distribution contributing to a heavier right tail.

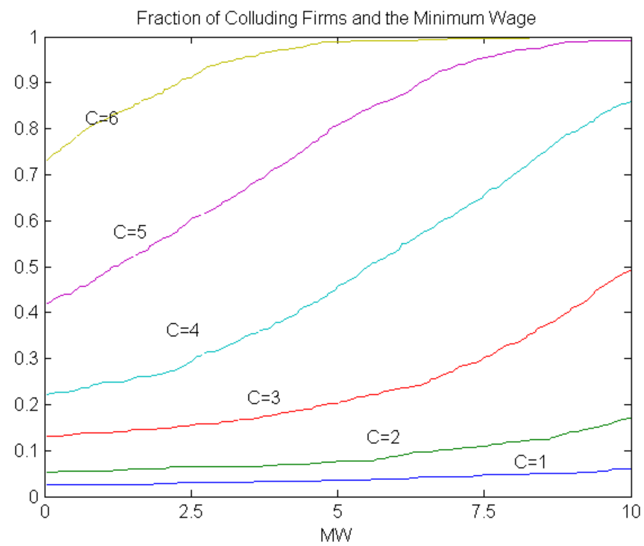

Figure 3: MW Levels and the Spike Size

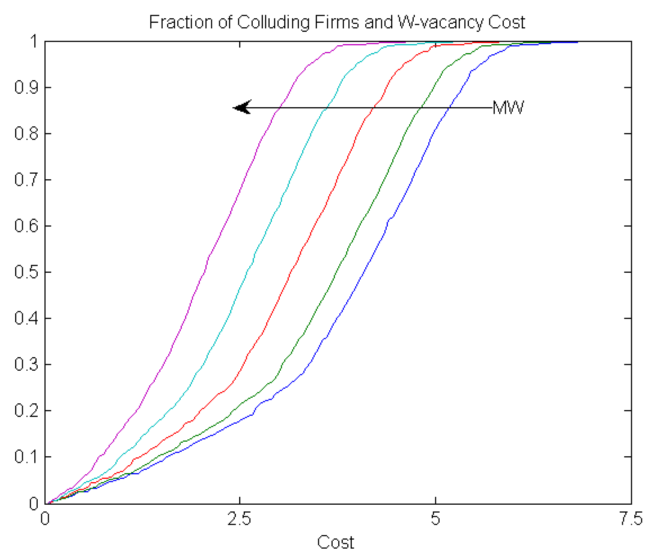

Figure 4: Cost and the Spike Size

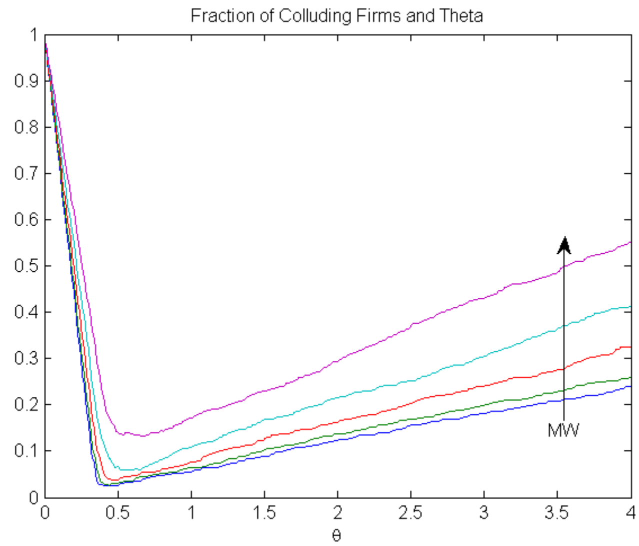

Figure 5: Market Tightness and the Spike Size

leads to greater collusion. Given the same w-vacancy cost, a higher minimum wage produces a larger coalition. The change in the propensity to join the coalition is not constant along the specified cost interval: it is slower for low and high cost values, and faster for mid-values.

The effects of the labor market tightness are demonstrated in Figure 5. The graph shows that the relationship between θ and the size of the coalition is non-linear. For low values of θ (roughly under 0.5) an increase in the number of vacancies per worker leads to a decrease in the propensity to collude. However, for larger vacancy-to-unemployment ratios propensity to collude is rising along with the number of vacancies per worker. In other words, the greater the employer competition, more likely they will collude. Two possible explanations for this outcome can be offered. First, the larger the size of the market, the larger the support of the wage distribution. Thus, a representative firm with a fixed productivity endowment will pay a higher wage the more employers are out there competing for a limited pool of labor. Second, a larger number of vacancies make collusion more attractive by affecting the relative probability of forming a match and increasing the expected payoff to colluders.

Lastly, the two panels in Figure 6 illustrate the relationships between the propensity to form collusive coalitions and the mean/variance of the produc-

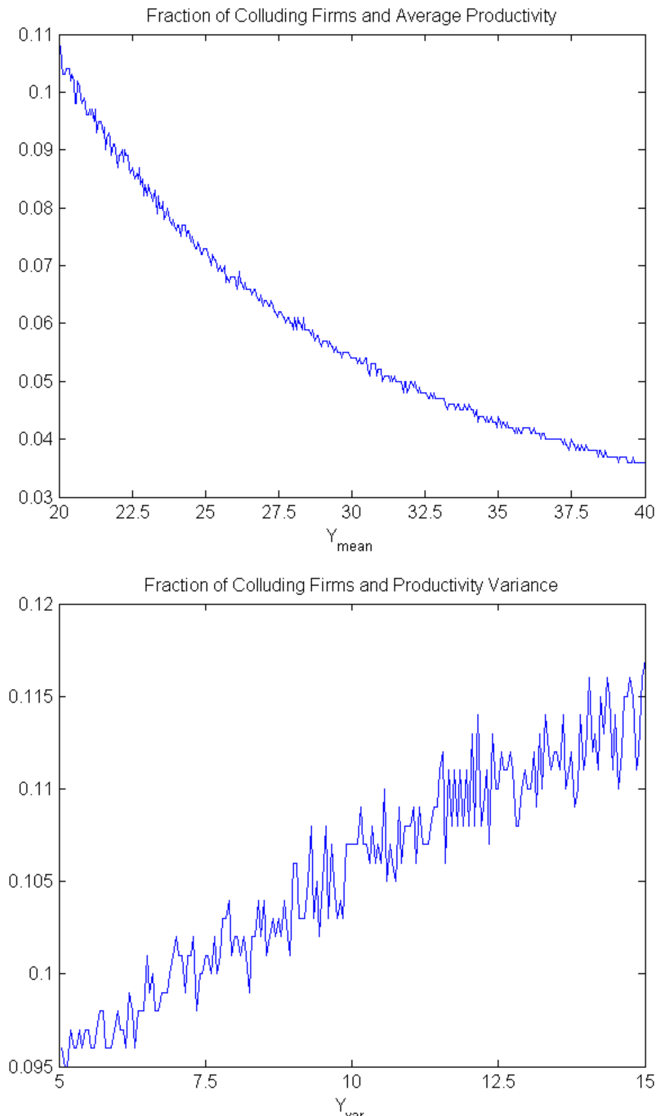

Figure 6: Productivity and the Spike Size

tivity distribution. First, it is clear that the greater the average productivity, the smaller the size of the collusive fraction. This again can be related to the discussed stylized fact regarding the eroding minimum wage, which can be alternatively modeled as a rising nominal productivity. The lower panel of Figure 6 shows that given the same distributional mean (mean(Y)=25), a higher variance leads to the greater propensity to collude. This can be easily explained: a higher variance extends the support of the productivity distribution upwards and, more importantly, downwards, inducing more low-productivity employers to join the collusive coalition.

This simple one-period model provided several interesting insights on how labor markets behave if a fraction of wage-setting employers succeed in forming a collusive coalition at the lowest allowed wage. In accordance with theoretical predictions and empirical facts, the minimum wage spike is greater when the minimum wage increases and it is smaller when it erodes. The model also demonstrates that the labor market conditions that are unfavorable to employers facilitate cooperation, while the productivity growth weakens the incentive to cooperate.

4 Intertemporal Search Model

This section presents a model of intertemporal search similar to the model of Burdett and Mortensen (1998). The model explores the mechanism of the minimum wage spike formation in a greater detail.

Firms

As before, when determining wages, firms face a binary choice: they can either offer the minimum wage m or a higher wage w. Firm's lifetime discounted value of a vacancy is:

$$V_k = \frac{1}{1+r}\left[-C_k + p_k J_k + (1-p_k)\max\{V_m, V_w\}\right],$$

where C_k is the firm's vacancy cost;
– r is the interest rate;
– p_k is the probability of filling a vacancy;
– J_k is the value of a filled position;
and the subscript k takes values m and w.

It is assumed that $C_m < C_w$, i.e. firms face (self-impose) an additional cost of posting a vacancy that is higher than the minimum wage. I normalize the minimum wage vacancy cost C_m to zero and reduce the notation for C_w to C.

The firm's lifetime discounted value of a filled job is:

$$J_k = \frac{1}{1+r}\left[y - w_k + s\max\{V_m, V_w\} + (1-s)J_k\right],$$

where $w_k = [m, w]$ and y denotes firm's productivity.

Similarly to the single period, due to productive heterogeneity some firms find it optimal to offer the minimum wage, while others do not. Thus, for vacant firms that find it optimal to post minimum wage offers the Bellman equations are:

$$rV_m = p_m(J_m - V_m); \tag{8}$$

$$rJ_m = y - m + s(V_m - J_m). \tag{9}$$

Firms that find it optimal to post higher wages have the following Bellman equations:

$$rV_w = -C + p_w(J_w - V_w); \tag{10}$$

$$rJ_w = y - w + s(V_w - J_w). \tag{11}$$

Solving the Bellman equations for high productivity firms (for which $V_w > Vm$) simultaneously, the following vacancy value is obtained:

$$V_w = \frac{(y-w)p_w - C(r+s)}{r(p_w + r + s)}.$$

Wages are determined similarly to the single period model. In absence of the minimum wage the lowest wage is set at just above the common reservation wage. If the minimum wage is present, the lowest wage is the minimum wage. If there is collusion at the minimum, the first non-minimum wage is set at just above the minimum. The wage distribution has no gaps in the support: firms balance higher probability of filling the vacancies associated and lower per period payoffs with lower probability of filling vacancies with higher per period payoffs. Thus, a non-colluding firm's wage is found by equating:

$$V(y_j, w_j, p(\theta, F(w_j))) = V(y_j, w_{j-1}, p(\theta, F(w_{j-1}))),$$

with the optimal wage offer as:

$$w_j^* = y_j - \left(\frac{(y_j - w_{j-1})p_{j-1}a + C(r+s)(1-a)}{p_j}\right), \tag{12}$$

where $a = \frac{p_j + r + s}{p_{j-1} + r + s} > 1$ (since $p_j > p_{j-1}$).

As the expression indicates, the optimal wage offer for the non-colluding firms in the multi-period framework is similar to its single period counterpart with an addition of the interest rate and the separation rate. Both parameters have positive associations with equilibrium wage offers.

Symmetrically, low-productivity colluding firms ($V_m > V_w$) attach the following value to the vacancy:

$$V_m = \frac{(y - m)p_m}{r(p_m + r + s)}.$$

Thus, firm's optimal wage offer schedule is:

$$w = \begin{cases} m & \text{if } V_m \geq V_w; \\ w^* & \text{otherwise.} \end{cases}$$

The equality of V_m and V_w determines the boundary productivity $\widehat{y}$ that splits vacant firms into colluders and non-colluders.

Workers

Worker's Bellman equations are identical to the ones in the Burdett-Mortensen model:

$$rU = z - c + q(E - U);$$

$$rE = w + s(U - E),$$

where U is the lifetime discounted value of unemployment;
– E is the value of being employed;
– z is the value of leisure (or unemployment benefits);
– c is the worker's search cost;
and q is the probability of receiving a job offer.

Applying the reservation wage property $U = E$ yields the following reservation wage:

$$w_r = z - c.$$

If z and c both are equal to zero, workers accept any job offer, making the unemployment a consequence of matching frictions only.

Equilibrium

A stationary wage-posting equilibrium in which all aggregate quantities are constant is considered. Standard arguments apply: under given initial conditions there is at most one equilibrium in this economy[8].

The wage-posting equilibrium is a vector of endogenously determined variables $\{\{w_j\}_{j=1}^{M-V}, \{w_j^o\}_{j=1}^{V}, u, \theta, \rho^o, \rho\}$ consisting of:

- distribution of wages $\{w_j\}_{j=1}^{M-V}$;
- distribution of wage offers $\{w_j^o\}_{j=1}^{V}$;
- fraction of vacant firms offering the minimum wage ρ^o;
- fraction of occupied firms paying the minimum wage ρ;
- unemployment rate u;
- labor market tightness θ.

In equilibrium:

- vacant firms post wage offers by maximizing their values of vacancy, taking their productivity as given;
- workers apply to the highest wage vacancy and accept job if offered and if the wage exceeds their reservation wage;
- markets do not clear due to search frictions, resulting in equilibrium unemployment.

Simulation Results

The purpose of this section is to demonstrate the relationships between the model's variables: minimum wage level, firm productivity, collusion enforcement cost, wages and unemployment with the help of simulation exercises. The model's baseline parameters are given in Table 2. Results are recorded in Tables 3 and 4.

I start each set of the simulations by obtaining a benchmark economy for the three sets of values of Y and C. The minimum wage rates equal to \$10, \$12.5, and \$15, and are non-binding (lower than the smallest firm's productivity). Results of the simulations are in Tables 3 and 4.

[8]For instance, see Alvarez and Shimer (2008) for a general rationale.

Table 2: Baseline Parameters(2)

Number of firms, M	1,000
Number of workers, N	1,000
Value of leisure, z	0
Minimum wage, m	0
Separation rate, s	0.10
Interest rate, r	0.05

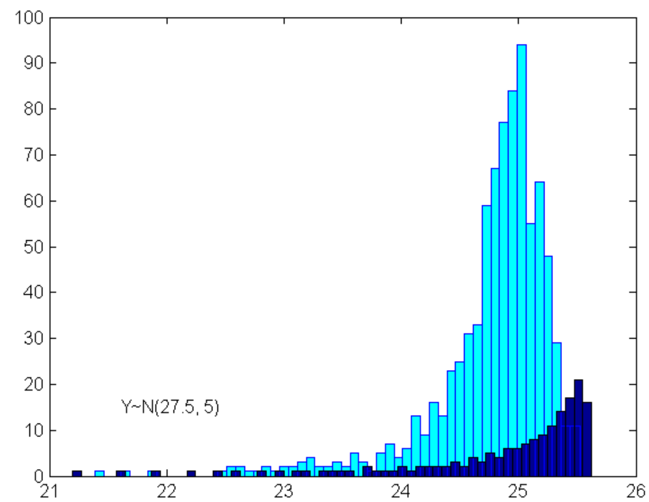

Figure 7: Wage/Wage Offer Distribution in Economy without MW

Benchmark unemployment rates, average wages and wage offers are displayed in the first column of the result tables. Note that average wages are always greater than average wage offers, consistent with empirical evidence. The results also show that vacancy values for the benchmark economy are lower than for the economies with collusive minimum wages, demonstrating an attractiveness of the equilibria with collusion. This is true for both colluding and deviating firms, even after accounting for the deviation penalty encountered by defectors. But more importantly, the models were able to replicate wage dispersion and the minimum wage spike (figure 7, 8) that is non-degenerate.

Under certain parameter values, namely under low productivity, high

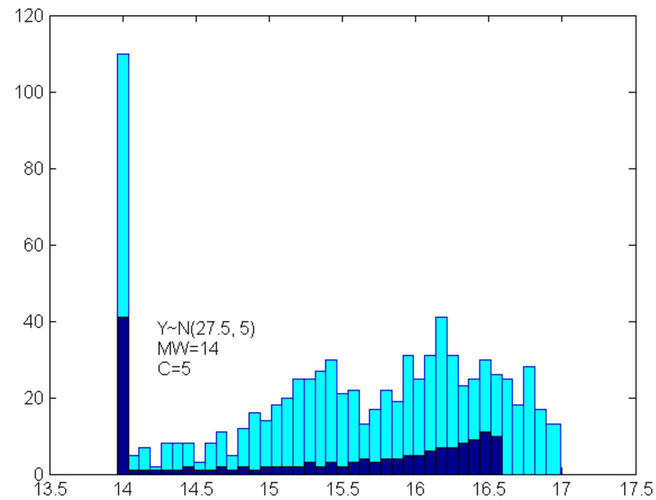

Figure 8: Economy with a Minimum Wage

minimum wage, or high cost of deviation, the wage distributions showed a tendency to converge to practically a single-wage minimum wage equilibrium (e.g., Table 3, MW=15, C=5 and Y∼N(22.5, 5)). Alternatively, when the cost of deviation or the minimum wage is low, the minimum wage spike is negligible (Table 4, MW=10, C=2.5).

Examination of the results for different productivity levels (Table 3) confirms that greater productivity or the eroding minimum wage create stronger incentives to deviate from the cooperative path. As a result, the minimum wage spike decreases (consistent with the pattern in Figure 2), wage and wage offers rise, however, it coincides with a rising unemployment. Similarly to the single period model a higher minimum wage induces greater collusion.

Importantly, simulations results also reveal that the existence of the minimum wage spike leads to a reduction in the unemployment rates, and the larger the spike – the greater the reduction. The drop in unemployment rates is explained by increasing matching efficiency: the mass of identical wage offers results in workers' drawing identical offers, and leads to a random choice between them. The absence of sorting, as in the case of favoring a higher wage, reduces the congestion externality since fewer workers now compete for the same high offers. Thus, a higher minimum wage can be

Table 3: Simulation Results Under Different Productivities (C=5)

Y(22.5,5)	Benchmark	MW \$10	MW \$12.5	MW \$15
Unemployment rate, %	14.97	14.57	13.69	13.61
Average wage offer	20.00	10.25	12.50	15.00
Average wage	20.64	10.34	12.50	15.00
Percent of MW offers	0.00	56.30	99.85	100.00
Percent of MW wages	0.00	41.90	99.76	99.96
Matching efficiency, %	56.82	58.66	63.38	63.55
Average vacancy value	106.47	281.9	256.4	217.6
Y(25, 5)				
Unemployment rate, %	14.95	14.95	14.57	13.64
Average wage offer	22.19	12.57	12.73	15.00
Average wage	22.89	13.19	12.82	15.04
Percent of MW offers	0.00	17.44	57.25	99.85
Percent of MW wages	0.00	4.82	43.17	98.99
Matching efficiency, %	56.80	56.88	58.67	63.36
Average vacancy value	111.87	272.3	286.1	259.7
Y(27.5, 5)				
Unemployment rate, %	14.96	14.98	14.95	14.53
Average wage offer	24.32	14.54	15.00	15.17
Average wage	25.08	15.41	15.69	15.31
Percent of MW offers	0.00	11.67	17.73	60.68
Percent of MW wages	0.00	2.12	4.86	46.70
Matching efficiency, %	56.72	56.78	56.84	58.96
Average vacancy value	116.72	269.6	267.8	281.94

Table 4: Simulation Results Under Different C-Values, Y∼N(25,5)

C=2.5	Benchmark	MW \$10	MW \$12.5	MW \$15
Unemployment rate, %	14.95	14.94	14.90	15.00
Average wage offer	22.19	15.99	16.35	16.87
Average wage	22.89	16.78	17.01	17.32
Percent of MW offers	0.00	5.53	8.05	14.14
Percent of MW wage	0.00	0.46	1.04	3.15
Matching efficiency, %	56.80	56.81	56.81	56.92
Average vacancy value	111.87	223.82	220.1	216.13
C=5				
Unemployment rate, %	14.95	14.96	14.57	13.64
Average wage offer	22.19	12.57	12.73	15.00
Average wage	22.89	13.19	12.82	15.04
Percent of MW offers	0.00	17.44	57.25	99.85
Percent of MW wage	0.00	4.82	43.17	98.99
Matching efficiency, %	56.80	56.88	58.67	63.36
Average vacancy value	111.87	272.3	286.1	259.7
C=7.5				
Unemployment rate, %	14.95	13.65	13.60	13.61
Average wage offer	22.19	10.00	12.50	15.00
Average wage	22.89	10.09	12.58	15.06
Percent of MW offers	0.00	100.00	100.00	100.00
Percent of MW wage	0.00	99.25	99.23	99.24
Matching efficiency, %	56.80	63.35	63.34	63.35
Average vacancy value	111.87	342.62	301.35	261.42

linked to lower unemployment which is consistent with a number of recent empirical studies. One can argue that the social efficiency can be improved in the form of lower unemployment. Note, however, that this result holds only when the minimum wage in non-binding and there is no displacement of firms.

While the minimum wage that serves as a reference point for collusion can improve employment outcomes, the wages in the economy with the collusive minimum wage are generally lower than in the benchmark economy without the minimum. At the same time a higher minimum wage is shown to raise wages, which is also reflective of empirical observations.

What is also worth noticing from the results is the speed of wage growth in an economy with and without the minimum wage, and under different minimum wage levels. When average firm productivity rises from 22.5 to 25 to 27.5, the wages in the economy without the minimum grow at an average rate of about 10% (roughly a $2 increase). In the economy with low minimum wages ($10), the wages rise at the rate of 27% and 16% respectively (for $3 and $2 increases). In the economy with a high minimum wage ($15) the wages hardly rise at all.

Generally, a more costly deviation from the cooperative strategy tends to reduce unemployment (through a reduction in the congestion externality (Table 4) as well as to decrease wages. Though collusion at the minimum wage is an attractive alternative for employers, vacancy values for employers differ at different minimum wage levels. For instance, when the w-vacancy cost is set at $2.5, firms enjoy greater vacancy values at MW=$10. At C=$5 the preferred minimum wage is $12.5, and at C=$7.5 – the preferred minimum is $10. But generally, for our experiments when the minimum wage is non-binding, a higher enforcement cost should be preferred by employers.

5 A Calibration Primer

To further check the validity of the model predictions I calibrate the model to the two-step federal minimum wage hike of 1996-97, concentrating on the group of high-school dropouts in the states with the federal minimum (in the US). As the model does not allow entry and job creation, I am limited to considering the very short-run effects of the minimum wage increase. Thus, for the October 1996 minimum wage hike I compare the market data for the months of September and October. For the September 1997 minimum wage increase I use data from May and September, attempting to minimize the seasonal labor market movements associated with summer months.

Table 5 presents calibration targets. Wages and employment data presented in the table is calculated using the CPS MORG earnings extracts and excludes observations with hourly wages below $1.50 and above $150. Estimates are weighted by CPS earnings weights. In addition, I remove the 1st and the 99th wage percentiles of the remaining data.

I calibrate model using monthly parameter values. I use monthly interest rate $r = 0.005$, equivalent to the discount rate of 0.995. Another exogenous parameter is the separation rate s. Abowd and Zellner (1985) report the average of 3.42% of all employed workers exit employment during a typical month. Pallage and Zimmermann(1997) calculate the probability of transition from employment to unemployment for the US workers with less-than-high-school education at 5.14%. JOLTs separation rates in retail

Table 5: Wages and Employment of High-School Dropouts, 1996-1997

	% MW obs.	Wage Mean	Wage St.Dev.	Unempl.	CPI-U (1982=100)
1996 MW Increase:		*MW=\$4.25 ⇒ MW=\$4.75*			
Before (Sep 96)	6.87	7.44	3.29	5.67	156.3
After (Oct 96)	7.71	7.73	3.27	5.22	157.8
1997 MW Increase:		*MW=\$4.75 ⇒ MW=\$5.15*			
Before (May 97)	6.25	7.82	3.17	6.07	160
After (Sep 97)	7.60	7.83	2.79	5.86	161.2

sector, the largest employer of high-school dropouts, ranges from 4 to 5% per month (for 2001-2008, since beginning of the JOLTs publication). In the calibration I use the separation rate of 0.04.

For the distribution of the firm productivity I chose to use lognormal distribution motivated by the fact that the empirical wage distribution of high school dropouts is skewed to the right. The mean and the variance are set at (4.2, 0.325), the values that allow to obtain average wage and collusion values reflective September 1996 data. These log-normal values imply, however, that the firm productivity is significantly higher than the wage paid. The productivity distribution parameters for further dates are adjusted by the CPI-U values, also given in the table above. The collusion enforcement costs are set as a fraction of productivity, at 0.38*Y.

Table 6 presents calibration results, reflecting the averages of 44 runs (repetitions of the same experiment) and associated standard errors. When calibrating, one obstacle was encountered. Namely, it was rather difficult to obtain a large enough variance of the wage (and required further increases in the mean productivity, which was already rather high). This can be explained by the divergence between the model market and the data. The model assumes that employers are able to perfectly observe a competitor's productivity, wage and rank. The data that I use is the national level data, and may reflect major wage differences across localities. However, the direction of change in the calibrated wage variance is generally consistent with the data.

Calibration results demonstrate that the increasing minimum wage, in both the model and the real economies, of 1996-97 increased fractions of

Table 6: Calibration Results

	% MW	Wage		Unempl.
	obs.	Mean	St.Dev.	
1996 MW Increase:	*MW=$4.25 ⇒ MW=$4.75*			
Before	6.346	7.307	1.359	6.572
	(0.049)	(0.014)	(0.014)	(0.012)
After	6.928	7.662	1.322	6.566
	(0.050)	(0.008)	(0.005)	(0.013)
1997 MW Increase:	*MW=$4.75 ⇒ MW=$5.15*			
Before	6.901	7.601	1.302	6.559
	(0.051)	(0.007)	(0.005)	(0.010)
After	7.311	7.950	1.315	6.546
	(0.049)	(0.004)	(0.007)	(0.011)

minimum wage workers as well as wages. The decrease in the wage standard deviation due to the higher minimum wage was obtained only in the 1996 calibration. However, the overall trend in the standard deviation to decline from 1996 to 1997 was replicated.

The higher minimum has also been shown to reduce unemployment, though the percentage changes obtained in the calibrations are much smaller than actuals. This is explainable since the model captures only the frictional portion of the overall unemployment and the actual changes could be larger due to changes in other types of unemployment. The calibrated unemployment rates were also smaller than the actuals. The unemployment has shown to be roughly 50% higher than the separation rate since the matching efficiency was in 55-60% range, and if needed the chosen separation parameter can be adjusted.

6 Conclusion

The empirical wage and wage offer distributions in the market with mandated minimum wages exhibit both the minimum wage spike and the wage dispersion. In the wage-posting environment where firms are heterogenous in their productivity, one would expect the latter but not the former, as competition for the limited pool of labor pushes firms to compete and pay differentiated wages, balancing out the probability of forming a match with lower profits.

This paper attempts to reconcile the two empirical phenomena. I build on the wage-posting framework of Burdett and Mortensen (1998), with heterogenous employers, perfect monitoring and urn-ball type of matching, adding a model feature that allows me to obtain the minimum wage spike. Namely, I assume that vacant employers choose between colluding at the minimum wage and posting a wage that is higher than the minimum in the environment where defection is penalized. This Prisoners' Dilemma type of choice results in the equilibrium outcome where a cooperative outcome is preferred by some employers and not attractive to others.

Curiously, in such environment the collusive (partial or full) equilibrium is superior to the 'competitive' from the employers' perspective. Since the payoffs are greater under collusion, even after accounting for the penalty, these potential rents can promote changes in the market mechanism of wage determination. The evolution of the labor markets can bring about this change as well, the kind that was observed for the past few decades, when the minimum wage vacancies became rather visible, thus increasing the advertising and recruiting costs for non-minimum wage employers.

The collusive outcome also promises lower frictional unemployment, since the amount of wage sorting by workers is reduced. However, a higher employment comes at the cost of lower wages and greater wage compression, when contrasted to the economy without the collusion enforcement mechanism.

In addition to replication of the spike and wage dispersion, the model was able to replicate such empirical observations as higher wages and lower unemployment resulting from the hikes in the minimum wage. The constructed model can also potentially explain zero or negative employment outcomes, if the minimum wage becomes binding and entry/exit is allowed.

Thus, the paper continued the discussion of the controversial effects of the minimum wage. A couple of policy lessons can be drawn from the paper. A policy-maker should not only assess how binding the minimum wage is, but also understand the underlying mechanisms of wage determination (e.g., wage-posting versus wage-bargaining), the nature of the matching process (e.g., sequential or simultaneous drawing of wage offers), as well as the existing or emerging incentives for cooperative behavior. Depending on these market characteristics, the minimum wage effects could be quite different.

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