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Effects of minimum wage on workers' on-the-job effort and labor market outcomes[☆]

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ABSTRACT

Can higher minimum wages motivate workers to work harder? If so, what are the effects of workers' on-the-job effort responses on the labor market outcomes? To answer these questions, we apply a model with directed on-the-job search and dynamic incentive contracts in a frictional labor market. The steady-state comparison of the calibrated model shows that a higher minimum wage increases workers' on-the-job effort. It also reduces the average hiring and layoff rates. Since the reduction in the hiring rate is higher than the reduction in the layoff rate, the un-employment rate increases, and hence lowers the aggregate output. Moreover, we find that the higher minimum wage has a spillover effect on higher-income workers. It suggests that agents' incentive decisions can provide a new explanation of the spillover effect of the minimum wage. Lastly, shutting down the effort channel leads to greater labor market impacts. These results suggest that workers' on-the-job effort responses have moderate offsetting effects on the cost of the higher minimum wage.

1. Introduction

Recent studies have shown that a higher minimum wage can contribute to higher labor productivity (Croucher et al., 2012; Riley and Bondibene, 2017; Ku, 2018; Coviello et al., 2019). However, the observed positive relationship between the minimum wage and labor productivity cannot distinguish between (1) the selection effect: firms can choose to dismiss (or not hire) low productive workers; and (2) the incentive effect: workers can increase their on-the-job effort and hence productivity to preempt layoffs. While many studies focus on the selection problem, the incentive effect is mostly overlooked in the literature, mainly due to the difficulty in measuring effort. In this paper, we apply the directed search model with dynamic incentive contracts developed by Tsuyuhara (2016b) to analyze the impacts of minimum wages on workers' optimal choice of on-the-job effort and the effects of this effort responses on the labor market outcomes.

In the model, workers' probability of being laid off depends on their exerting on-the-job effort. In the meanwhile, workers search for better offers if they can stay at their current job. Firms design contracts to induce workers' unobservable effort, which positively affects the output. In addition, search is assumed to be directed. That is, all firms post contracts on the labor market. Each worker observes all offers and chooses the most attractive one to apply for. When making search decisions, firms and workers take into account the trade-off between the value of an offer and the matching rate at the offer. If a new minimum wage is introduced, firms need to adjust the contracting decisions corresponding to workers' effort responses, which will further affect workers' and firms' search decisions. Such directed search framework that incorporates workers' work effort responses allows us to analyze the effects of minimum wage on the behavior of both the labor supply and demand sides.

We calibrate the model to the U.S. labor market using the Current Population Survey (CPS) for September 1997 to December 2006.[1] The calibrated model shows that a 5% increase in the minimum wage raises the unemployment rate by 2.35%. This is because the higher minimum wage increases the labor cost, which drives firms out of the market. Moreover, since the exit of firms makes jobs harder to find, the higher minimum wage lowers the average hiring rate by 2.66%.[2] On the other

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[1] The statutory minimum wage in the U.S. remained unchanged ($5.15) over this period.
[2] The hiring rate is defined as the unemployment-to-employment transition rate.

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hand, the higher minimum wage raises the average workers' on-the-job effort by 0.26% and lowers the average layoff rate by 0.25%.[3] This is because employed workers will work harder to avoid being laid off as the lower hiring rate increases the cost of being laid off. Due to the higher unemployment rate, the aggregate output decreases by 0.1%, even with the higher average on-the-job effort. In addition, the higher minimum wage raises the average wage and the highest equilibrium wage. These results suggest that the higher minimum wage rises the pay for workers who previously earned above the new minimum wage. This is because the employed workers are more willing to exert effort in order to avoid being laid off. The increase in the supply of effort lowers the price of workers' on-the-job effort. With the relatively elastic demand, the firms' spending on effort (wage) increases.

To highlight the role of workers' on-the-job effort, we shut down the effort channel and recalibrate the model. Since firms do not respond to the higher minimum wage by inducing workers' effort, the higher labor cost cannot be compensated by the rise in the effort. As a result, more firms are driven out of the market, and the unemployment rate goes up by 2.59%. Since more firms exit the market, the average hiring rate decrease by 2.68%. The higher minimum wage also lowers the aggregate output by 0.12%. Moreover, since firms do not induce workers' on-the-job effort by paying higher wages, the average wage decreases by 0.025%. These higher negative impacts imply that workers' on-the-job effort has moderate offsetting effects on the costs of a higher minimum wage.

To the best of our knowledge, there are only two papers that directly estimate the effect of a higher statutory minimum wage on individual worker productivity.[4] Ku (2018) measures worker productivity using the average wage per hour of a large number of piece-rate workers who perform a homogenous task. She estimates the change in relative productivity for tomato pickers before and after the January 2009 minimum wage increase in the state of Florida. She finds that the higher minimum wage raises the individual worker productivity. Coviello et al. (2019) measure worker productivity using the sales per hour of base plus commission salespeople from a large US retailer. They estimate the absolute productivity change and also find that a higher minimum wage increases individual worker productivity. Besides, they find no evidence in favor of selective termination of workers across productivity types. Hence, they claim that the increased productivity comes from higher work effort. We view our analysis as complementary to Ku (2018) and Coviello et al. (2019) because we explicitly model the on-the-job effort channel and quantitatively show that a higher minimum wage increases workers' on-the-job effort.

A small body of literature takes into account incentives when analyzing the minimum wage policies. Owens and Kagel (2010) impose minimum wages in experimental gift-exchange markets. They find that higher minimum wages raise workers' effort provision and average wages. One primary concern of the laboratory gift-exchange results is the degree to which these mean anything in the field environment (Charness and Kuhn, 2011). In our study, we use a calibrated model with survey data to provide implications that minimum wage increases work effort and hence productivity. Besides, our findings are consistent with Owens and Kagel (2010). Kadan and Swinkels (2013) analyze the effect of the minimum wage within a standard moral hazard framework.[5] They show that minimum wage has negative impacts on induced effort level. This is because higher minimum wage increases the marginal costs of inducing effort. In contrast, the current model incorporates equilibrium interactions between incentive decisions and the outside option. By taking the outside option into account, we find that minimum wage has a positive impact on induced effort level.

A handful of papers in the literature have directly estimated the effects of minimum wages on labor market transition rates. Portugal and Cardoso (2006) study the separations and hires of teenagers before and after a youth-specific minimum wage increase in Portugal. They find that both the teen share of separations and hires declined due to the increase in the minimum wage. Brochu and Green (2013) use Canadian data and find that higher minimum wages result in lower hiring, quit, and layoff rates of unskilled workers of all ages. Dube et al. (2016) use pairs of counties across state borders in the U.S. to control for spatial heterogeneity. And they find significant adverse effects of the minimum wage on hiring and separation rates, particularly for teenagers and in the restaurant workforce. This paper is complementary to those studies in the sense that it indicates workers' optimal choice of effort plays an important role in mediating the effects of minimum wage on labor market transition rates.

Lastly, this paper is also related to the literature addressing the issue of the spillover effect of minimum wages.[6] Grossman (1983) is the first study that attempts to estimate the spillover effects of minimum wages directly. She finds that an increase in minimum wage increases the wages of occupations above the new minimum wage. DiNardo et al. (1996) and Lee (1999) examine the changes in the U.S. wage distribution and find evidence of the spillover effect of the minimum wage. Neumark et al. (2004) estimate the impact of changes in the minimum wage on the wages of workers who previously earned above the new minimum wage. Their results suggest that minimum wage has substantial spillover effects on the higher wage group. Two broad alternative classes of explanations have been proposed for the spillover effect. The first explanation builds on the monopsonistic competition among firms for workers. The other emphasizes that workers' job satisfaction and productivity are affected by their level of wages relative to their colleagues (Fehr and Schmidt, 1999; Card and Krueger, 2015). This paper contributes to the literature by showing that the general equilibrium effect of minimum wage on workers' optimal choice of effort and firms' contracting decisions can provide a new explanation of the spillover effect.

This paper proceeds as follows. In section 2, we present the theoretical model. Section 3 describes the model calibration strategy and discusses how does the minimum wage affect workers' on-the-job effort and labor market outcomes. The robustness is provided in section 4, and section 5 concludes.

2. Model environment

2.1. The labor market

Consider a labor market that lasts forever in discrete time, and time is indexed by t. There is a unit continuum of infinitely lived, *ex-ante* homogeneous, and risk-averse workers whose periodical utility function of consumption is $u(\cdot)$, which is strictly increasing, strictly concave, and twice continuously differentiable. Workers cannot save or borrow against their future income, so their consumption is wage w if employed or unemployment benefit b if unemployed. Employed workers exert unobservable effort e on the job each period, and the disutility of effort is given by $c(\cdot)$, which is strictly increasing, strictly convex, and twice continuously

[3] The layoff rate is defined as the employment-to-unemployment transition rate.

[4] There are a handful of studies that measure on-the-job effort outside the minimum wage literature. For example, Lazear et al. (2016) study the individual worker productivity during recent recessions. They focus on "technology based service" jobs and use a new computer-based monitoring system such as an ERP (Enterprise Resource Planning) system to track the on-the-job effort of each individual worker. He et al. (2019) use worker-level output to measure on-the-job effort and examine the severe air pollution effect on labor productivity.

[5] Kadan and Swinkels (2013) and the current model both assume that workers are risk-averse, the effort cannot be observed, and an explicit contract is feasible.

[6] The spillover effect of minimum wage refers to the impact of minimum wage on the pay for workers who previously earned above the new minimum wage. Comprehensive reviews of the empirical literature on spillover effects of minimum wages are provided by Card and Krueger (2015) and Neumark and Wascher (2008).

differentiable. Both employed and unemployed workers search for jobs with probability λe and λu, respectively. Each worker maximizes the expected lifetime sum of utilities discounted at rate $\beta \in (0, 1)$.

There is a continuum of *ex-ante* homogenous firms whose measure is determined by competitive entry. Entering firms create a vacancy and post a job offer at a flow cost $k > 0$. Depending on the employed worker's effort, a job in each period results in one of two possible outcomes: y, called *success*, with probability $r(e)$ and 0, called *failure,* with probability $1 - r(e)$. The probability of success function $r(\cdot)$ is strictly increasing, strictly concave, and twice continuously differentiable. If the project succeeds, the job continues in the next period; if it fails, the job is destroyed, and the worker becomes unemployed. Each firm maximizes the expected sum of profits discounted at the rate β. Firms announce wage-tenure contracts to recruit. A contract specifies the wage at each tenure length t, conditional on whether the worker stays with the firm. There is minimum wage legislation so that the wage offers cannot be lower than the minimum wage $w_{\min}$.

A worker may leave a job at any time if a job fails or if she finds a new job via on-the-job search. Firms are assumed to commit to the contracts. That is, once a contract is initiated, a firm cannot adjust it or respond to the worker's outside offers. Moreover, because the worker's effort is unobservable, firms need to design a contract to induce and compensate for the workers' efforts optimally. One can consider a contract as it specifies a wage profile $\{w_t\}_{t\geq 0}$ and a *recommended* effort profile $\{e_t\}_{t\geq 0}$. For a given wage and effort profile, workers can calculate a discounted lifetime expected utility that the contract would deliver, taking into account the possibility of job destruction and the worker's job-to-job transition. The utility delivered by a contract is referred to as the *value* of a contract and is denoted by x.

The labor market consists of a continuum of submarkets indexed by $x \in X = [\underline{x}, \bar{x}]$. A submarket x consists of all the firms that promise to deliver value x. The worker's job search is directed with respect to the value of job offers. That is, workers observe all the contracts and choose which submarket to visit. The tightness of a submarket $\theta(x)$ is defined as the ratio of vacant jobs to searching workers. The job-finding probability and job-filling probability in submarket x are given by $p(\theta(x))$ and $q(\theta(x))$, respectively. $p(\cdot)$ is strictly increasing, strictly concave, twice continuously differentiable, and satisfies $p(0) = 0, p'(0) < \infty$. $q(\cdot)$ is strictly decreasing, strictly convex, twice continuously differentiable, and satisfies $p(\theta) = \theta q(\theta), q(0) = 1$. In addition, the matching technology is assumed to satisfy the condition that $p(q{-}1(\cdot))$ is concave.

Let the value of contract x and the value of unemployment U represent the worker's employment state in some periods. Let G_t denote the distribution of workers over X in period t. The fraction of unemployed workers in period t is $u_t = G_t(U)$. The evolution of the state is generically denoted by an operator Ψ so that $G_{t+1} = \Psi(G_t)$, where Ψ is endogenously determined according to workers' job search and firms' contracting decisions.

2.2. Job search problem

A worker who gets the opportunity to search chooses which submarket to enter, taking into account the value of the job offer and the probability of finding a job in each submarket. The optimal job search decision depends on the reservation value. For an employed worker, her reservation value is the value of her current contract for the rest of her life. For an unemployed worker, her reservation value is the value of unemployment. Consider a searching worker whose reservation value is W. If she visits submarket x, she gains net value of search $x - W$ with probability $p(\theta(x))$. Thus, her optimal job search decision maximizes $p(\theta(x))x + (1 - p(\theta(x)))W$ with respect to x. The optimal net expected value of search given W is:

$$D(W) = \max_{x\in X} p(\theta(x))(x - W) \tag{1}$$

The worker's optimal search policy given W is denoted by $m(W)$. Given $m(W)$, the probability of a worker successfully finding a job is given by the composite function $\hat{p}(W) = p(\theta(m(W)))$.

To define the value of unemployment, let U denote the value of unemployment. In the current period, unemployed workers receive and consume unemployment benefit b. In the next period, if an unemployed worker gets the opportunity to search for a job with probability λ_u, the expected lifetime utility is $U + D(U)$. Otherwise, the worker stays unemployed, which gives U. Since the unemployment benefit b is constant over time, the value of unemployment U satisfies the following recursive equation:

$$U = u(b) + \beta(U + \lambda_u D(U)) \tag{2}$$

2.3. Optimal contracting problem

Given the value V currently promised to the worker, the choices of a firm in the recursive contracting problem are the current wage w, the recommended effort e, and the reservation value W that the firm promises to deliver in the following period.[7] Let $J(x)$ denote a firm's value function of a job that offers a contract value x. The maximized value of a job $J(V)$ is expressed recursively by:

$$J(V) = \max_{\xi=\{w,e,W\}} r(e)y - w + \beta r(e)(1 - \lambda e\hat{p}(W))J(W) \tag{3}$$

subject to

$$V = u(w) - c(e) + \beta[r(e)(W + \lambda eD(W)) + (1 - r(e))U], \tag{4}$$

$$e \in \underset{e\in R}{\operatorname{argmax}}(-c(e) + \beta(r(e)(W + \lambda eD(W)) + (1 - r(e))U)), \tag{5}$$

$$W \in \{X : J(W) \geq 0\}, \tag{6}$$

$$w \geq w_{\min} \tag{7}$$

The firm's choice is subject to the promise-keeping constraint (4), which requires ξ to provide the worker with the lifetime utility V, the incentive compatibility (IC) constraint (5), which requires the contract to induce the worker to voluntarily exert the desired level of effort, the individual rationality (IR) constraint (6), which requires that the firm does not choose a continuation value that leads to a negative value, and minimum wage constraint (7), which requires that the minimum wage legislation is binding.

2.4. Competitive firm entry and market tightness

During the search stage, a firm chooses what contract to offer to attract a searching worker. The firm's expected value of opening a vacancy in submarket x is given by $q(\theta(x))J(x)$. For a given $\theta(x)$, if the cost k of creating a vacancy is strictly greater than the expected value, then no firm offers a contract with value x. If k is strictly smaller than the expected value, then there are an infinite number of firms offering contracts with value x. Therefore, in any submarket that is visited by a finite and positive number of workers, the market tightness $\theta(x)$ is consistent with the firm's optimal job creation strategy if and only if

$$q(\theta(x))J(x) - k \leq 0, \tag{8}$$

[7] To prove the existence of a recursive equilibrium, Tsuyuhara (2016b) introduces a lottery and allows the firm to randomize over these choices. The purpose of introducing the lottery is to guarantee that the firm's optimal value function J is concave. However, computed examples show that the firm's value function is concave without lottery for all the parameter configurations, which implies that the lottery is not used at the optimal. Since the purpose of this study is to solve the model numerically and describe some quantitative features, the lottery is excluded in the model description.

and $\theta(x) \geq 0$, with complementary slackness.

2.5. Block Recursive Equilibrium

Definition. A Block Recursive Equilibrium (BRE) *consists of the set of individual objects {D*, m*, U*, J*, ξ*, θ*} and the operator Ψ* such that*

1. The value of job search D* and the optimal search policy m* satisfy Equation (1).
2. The value of unemployment U* satisfies Equation (2),
3. The value of firm J* and an optimal contract policy ξ* satisfy Equation (3),
4. The market tightness θ* satisfies condition (8),
5. Ψ* *is derived from the optimal policy functions, ξ* and m*, and*
6. The individual objects {D*, m*, U*, J*, ξ*, θ*} are independent of the distribution of workers G^*_t for all t.

The existence of the BRE and the qualitative characterizations are discussed in Tsuyuhara (2016b).

3. Policy experiments

In this section, we first solve the model numerically. Then, using the calibrated model, we study how a higher minimum wage affects workers' optimal choice of on-the-job effort and labor market outcomes such as unemployment rate, aggregate output, labor market transition rates, and average wage. To highlight the role of workers' on-the-job effort, we mute workers' effort decisions and compare the results with those from the model with workers' effort decisions.

3.1. Model calibration

To solve the model numerically, we first impose functional forms to compute the model's steady-state. The worker's utility function is assumed to be a standard CRRA utility function $u(w) = \frac{w^{1-\sigma}}{1-\sigma}$, where σ is the CRRA coefficient. The disutility of effort is $c(e) = \frac{1}{2}e^2$. The matching technology is summarized by the employment probability function $p(\theta) = \theta(1+\theta^\gamma)^{-1/\gamma}$, where θ captures market tightness. The probability of success is given by a function $r(e) = \exp(-\frac{\rho}{e})$. The functional forms are collected in Table 1.

Given the choices of functional form, we have ten parameters which are needed to compute the model's equilibrium. The parameter values are documented in Table 2. The model period is set to be a month. Following Tsuyuhara (2016a), we set the discount factor β equal to 0.996. The CRRA coefficient σ equals to 2, which is a standard value in the literature. Following Menzio and Shi (2010), the matching technology parameter γ is set to be 0.5 so that the elasticity of substitution between vacancies and applicants is 2/3. The production level of a successful project y is normalized to 1.

There are six parameters left to be calibrated, and these are chosen by solving the model. The unemployment benefit b is 0.385, so that b is 40% of the average wage (Shimer, 2005). The vacancy cost k, worker productivity ρ, unemployed worker's search probability λ_u, employed worker's search probability λ_e, and the minimum wage $w_{\min}$ are jointly set so that the computed average hiring rate and layoff rate match the empirical moments in the U.S. data. Following the process described in Shimer (2012), we use the Current Population Survey (CPS) for September 1997 to December 2006 to compute the U.S. average hiring and layoff rates of all workers aged 16 and above.[8] Table 3 summarizes the calibration results. The calculated hiring rate, layoff rate, and replacement rate match their empirical counterparts. In addition to the target moments, the model also generates a reasonable unemployment rate and the share of the minimum wage workers.

Table 1
Functional form assumptions.

Utility function	$u(w) = \frac{w^{1-\sigma}}{1-\sigma}$
Effort cost function	$c(e) = \frac{1}{2}e^2$
Matching function	$p(\theta) = \theta(1+\theta^\gamma)^{-1/\gamma}$
Probability of success function	$r(e) = \exp(-\frac{\rho}{e})$

Table 2
Parameter values.

β-Discount factor	0.996
σ-CRRA	2
γ-Matching technology	0.5
y-Output level	1
b-Unemployment benefit	0.385
k-Vacancy creation cost	0.218
ρ-Worker productivity	0.0036
λ_u-Probability of search (unemployed)	0.8
λ_e-Probability of search (employed)	0.75
w_{min}-Minimum wage	0.7

3.2. Effects of minimum wage

Consider an increase in the minimum wage by 5% from the above benchmark calibration.[9] Table 4 summarizes the effects after the minimum wage change. First, the average work-ers' effort level increases by 0.26%, suggesting that the higher minimum wage contributes to higher labor productivity.[10] Furthermore, the unemployment rate rises by 2.35%.[11] Due to the higher unemployment, the aggregate output decreases by 0.1%. The average hiring and layoff rates decrease by 2.66% and 0.25%, respectively. Besides, the average wage increases by 0.018%.

The hiring rate is lower after the minimum wage change for the following reasons. First, the higher minimum wage decreases the value of

[8] The statutory minimum wage in the U.S. remained unchanged ($5.15) over this period.

[9] For the minimum wage to be nontrivial, we assume that the minimum wage is higher than the lowest equilibrium wage in the absence of the minimum wage, which is also true in the model calibration. We use a 5% increase because this is a calibration exercise using few empirical moments to pin down model parameters, and small deviations from the benchmark level of the minimum wage would provide more reliable results.

[10] Comparing to the empirical studies, the effort effects in this paper are small. One potential reason is that the calibrations in this study focus on all workers aged 16 and above. On the other hand, empirical studies on minimum wage effects often focus on the teens and/or the restaurant workforce because a high proportion of them work for minimum wage. Simply calibrate the model using different groups of workers cannot provide any reasonable comparison of the minimum wage effects across different workers. This is because the productivity y is assumed to be the same across workers in the current model. However, the productivity of the teens and the restaurant workers are likely to be different. Thus, in order to conduct reasonable comparison, the heterogeneity in worker productivity needs to be introduced in the current model, which is beyond the scope of this study. The main focus of this study is to highlight the explicit on-the-job effort channel and quantitatively show that a higher minimum wage increases workers' on-the-job effort.

[11] Card and Krueger (1994) find the increase of minimum wage leads to more employment in the state of New Jersey. In contrast, our findings suggest that a higher minimum wage leads to less employment. However, our findings do not contradict Card and Krueger (1994). This is because in the current model, depending on the parameters, the minimum wage effect on unemployment is ambiguous. For example, if the coefficient of risk aversion is higher, the workers are more afraid of being unemployed. A higher minimum wage can allow firms to induce more effort from the workers and overcome the increase in the labor cost. Thus, the unemployment rate decreases with higher minimum wage.

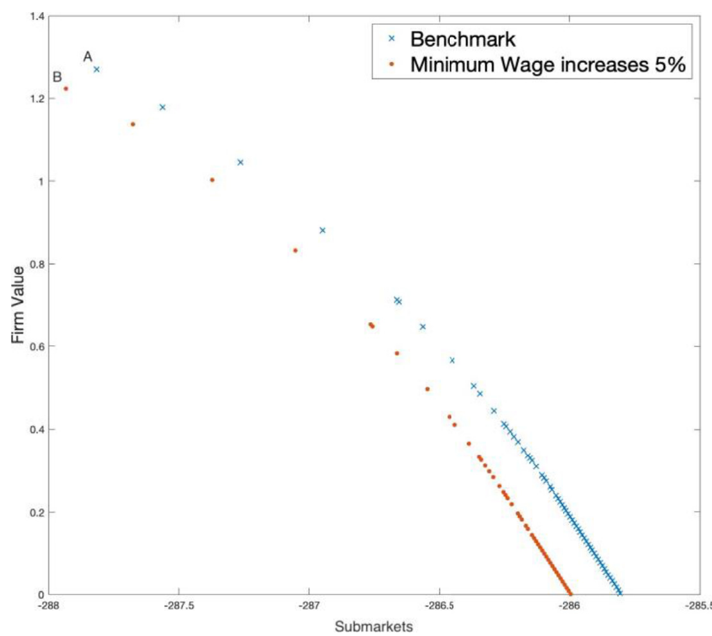
Table 3
Calibration targets.

	Data moments (CPS 1997.9–2006.12)	Model moments
Average hiring rate	27.99%	27.45%
Average layoff rate	1.243%	1.221%
Replacement	40%	39.81%
Unemployment rate	4.97%	4.26%
Share of minimum wage workers	1.79%	1.22%

Note: The hiring rate is defined as the unemployment-to-employment transition rate. The layoff rate is defined as the employment-to-unemployment transition rate. The share of minimum wage workers includes those who paid below the prevailing federal minimum wage.

Table 4
Effect of a 5% increase in minimum wage.

	Baseline	↑ by 5%	Change (%)	Percentagepoint difference	Elasticity
Average effort	0.29306	0.29383	0.26↑	–	0.05
Average hiring rate	27.45%	26.72%	2.66↓	0.73↓	−0.53
Average layoff	1.221%	1.218%	0.25↓	0.007↓	−0.05
Unemployment rate	4.26%	4.36%	2.35 ↑	0.1↑	0.48
Aggregate output	0.94572	0.94475	0.1↓	–	−0.021
Average wage	0.9672	0.96737	0.018↑	–	0.0036
Highest equilibrium wage	0.9877	0.9878	0.01↑	–	0.002



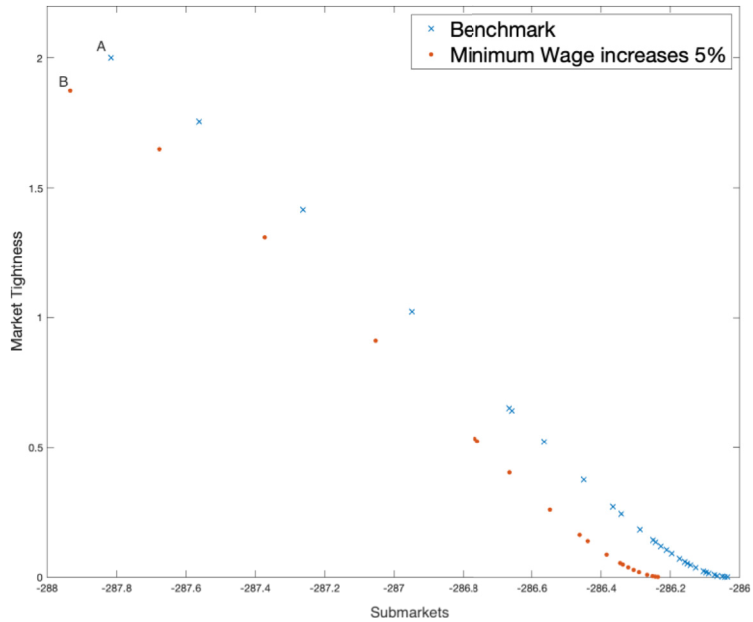
Notes: Point A represents the value for firms that offer minimum wage before the minimum wage change. Point B represents the value for firms that offer minimum wage after the minimum change. The figure implies that an increase in the minimum wage by 5% from the above benchmark calibration reduces the value for firms that offer a minimum wage.

Fig. 1. Firm value.

the firms who are in the minimum wage market. This is because the higher minimum wage increases the production cost of firms. On the other hand, a higher minimum wage also increases minimum wage workers' cost of being laid off. Thus, those workers will work harder to avoid being laid off. Since the rise in the on-the-job effort cannot adequately compensate for the increases in the production cost, firms' value is lower after the minimum wage change. As shown in Fig. 1, the value of the firms that offer minimum wage before the policy (Point A) is higher than the value after the policy (Point B). Besides, recall condition (8), a lower firm's value implies a "thinner market" (smaller θ) and a lower job-finding probability. As shown in Fig. 2, the minimum wage market becomes thinner after the minimum wage rise. Since an unemployed worker always searches in the minimum wage market, the average job-finding probability of unemployed workers (hiring rate) is lower.[12]

The calibration results also suggest that the policy reduces the value

[12] An unemployed worker always searches in the minimum wage market for the following reasons: First, as discussed in Tsuyuhara (2016b) (Lemma 1 and Proposition 3), wage and effort are monotone in the value of contract. Therefore, the contract with minimum wage provides the lowest value among the equilibrium offers. In addition, the job-finding probability is strictly decreasing with contract value. With directed search, low-value workers optimally choose to search for offers with relatively low value because those offers are easier to get (Lemma 4.1 in Menzio and Shi (2010) and Lemma 3.1 in Shi (2009)). Thus, an unemployed worker always targets on the minimum wage market.



Notes: Point A represents the market tightness for the submarket that offers minimum wage before the minimum wage change. Point B represents the market tightness for the submarket that offers minimum wage after the minimum wage change. The figure implies that an increase in the minimum wage by 5% from the above benchmark calibration reduces the market tightness for the submarket that offers a minimum wage.

Fig. 2. Market tightness.

of being un-employed.[13] Recall Equation (2), an unemployed worker's value is determined by her expected value of job search, $D(U)$.[14]. As discussed above, the higher minimum wage lowers the unemployed worker's job-finding probability, which would further decrease her expected value of job search. Thus, the higher minimum wage lowers the value of being unemployed.

An employed worker chooses how much effort to exert by comparing the benefit of staying employed with the cost of being laid off. A lower unemployment value increases the cost of being laid off and thus encourages employed workers to exert effort. Fig. 3 shows the effort profile before and after the minimum wage change. As a result of the higher on-the-job effort, the average layoff rate decreases. However, due to the higher unemployment, the aggregate output despite the higher on-the-job effort.

Fig. 4 shows that the higher minimum wage causes all wages to shift up. Moreover, as shown in Table 4, the average wage and the highest equilibrium wage increase. These results suggest that the higher minimum wage rises the pay for workers who previously earned above the new minimum wage. This is because the employed workers are more willing to exert effort in order to avoid being laid off. The increase in the supply of effort lowers the price of workers' on-the-job effort. With the relatively elastic demand, the firms' spending on effort (wage) increases.

Empirical studies observe that the minimum wage has a "spillover effect," meaning that when the minimum wage increases the wages of workers who already were earning more than the minimum increase as well (e.g., Neumark et al., 2004; David et al., 2016; Harasztosi and Lindner, 2019). One explanation of the "spillover effect" is that the increase in the minimum raises the relative price of low-skilled labor. This may lead to a rise in the demand for certain types of more skilled labor (depending on substitutability) and hence to increased wage rates for certain types of workers already above the minimum (Pettengill, 1981). Another explanation emphasizes that workers' job satisfaction and productivity are affected by their level of wages relative to their colleagues (Fehr and Schmidt, 1999; Card and Krueger, 2015). In addition to the previous explanations, this paper suggests that workers and firms' optimal choice of incentives can be another source of the "spillover effect" of the minimum wage.

3.3. *The role of workers' on-the-job effort*

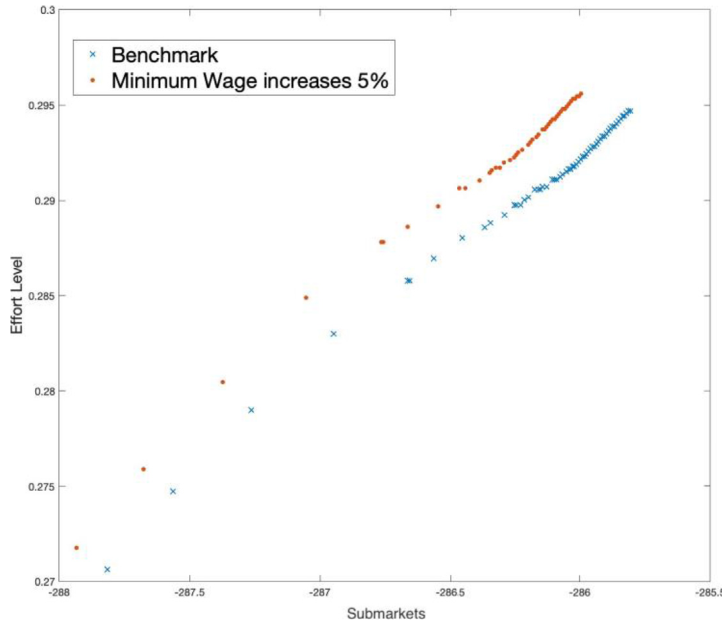
To highlight the role of workers' on-the-job effort, we shut down the effort channel and compare the results with those from the model with workers' on-the-job effort decision. For employed workers, the exogenous probability of being laid off is given by $\delta = 0.0124$. Table 5 summarizes the results. Since firms do not respond to the higher minimum wage by inducing workers' effort, the higher labor cost cannot be compensated by the rise in the effort. As a result, more firms are driven out of the market, and the unemployment rate goes up by 2.59%. Since more firms exit the market, the average hiring decrease by 2.68%. The higher minimum wage also lowers the aggregate output by 0.12%. Moreover, since firms do not induce workers' on-the-job effort by paying higher wages, the average wage decreases by 0.025%. These higher negative impacts imply that workers' on-the-job effort has moderate offsetting effects on the costs of a higher minimum wage.

4. Robustness

To examine the robustness of the above results, we first increase the minimum wage by 1% and 10%. Table 6 summarizes the results. Second, the level of risk aversion affects how workers evaluate the cost of being laid off and how they respond to the change of the minimum wage. Hence, we raise the coefficient of risk aversion to $\sigma = 3$. Table 7 summarizes the results of higher risk aversion. The quantitative magnitudes of the minimum wage effects depend on experiments, but the overall directions of changes are consistent with the baseline experiment.

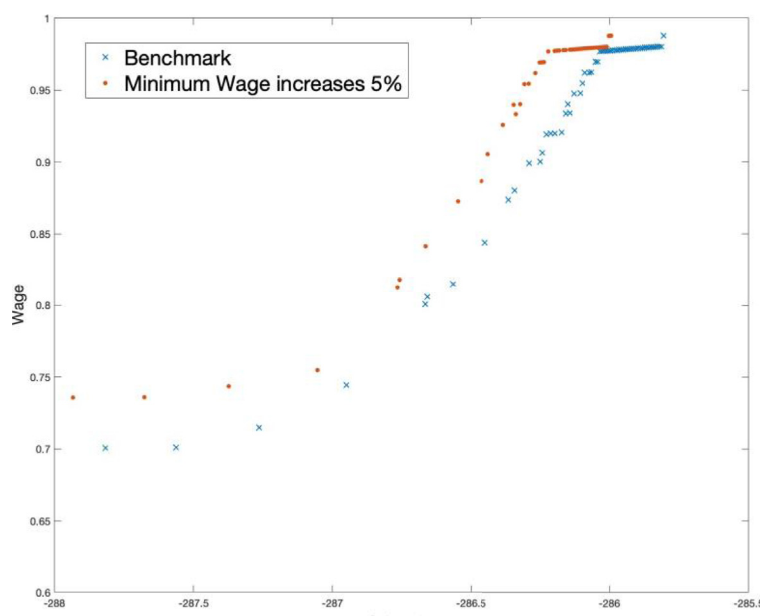
[13] The unemployment benefit decreases from -293.0228 to -293.2863.

[14] An unemployed worker's value is also determined by the unemployment benefit b and her search probability λu, which are exogenous in the model.



Notes: The figure illustrates that an increase in the minimum wage by 5% from the above benchmark calibration encourages employed workers to exert more effort, and thus lowers the employed-to-unemployed transition rates.

Fig. 3. Effort profile.



Notes: The figure illustrates that an increase in the minimum wage by 5% from the above benchmark calibration causes all wages to shift up.

Fig. 4. Wage.

Table 5
Effect of a 5% increase in minimum wage: Muting the effort channel.

	Baseline	↑ by 5%	Change (%)	Percentagepoint difference	Elasticity
Average effort	–	–	–	–	–
Average hiring rate	27.94%	27.19%	2.68↓	0.75↓	−0.54
Average layoff	1.24%	1.24%	–	–	–
Unemployment rate	4.25%	4.36%	2.59 ↑	0.11↑	0.52
Aggregate output	0.9575	0.95638	0.12↓	–	−0.024
Average wage	0.97797	0.97773	0.025↑	–	0.005

Notes: Layoff rate is determined by an exogenous job destruction rate $\delta = 0.0124$.

Table 6
Robustness: Effect of 1% and 10% increases in minimum wage.

	Baseline	↑ 1%	Change (%)	Percentage.point difference	↑ 10%	Change (%)	Percentage point difference
Average effort	0.29306	0.29307	0.003↑		0.29549	0.83↑	
Average hiring rate (UE)	27.45%	27.31%	0.51↓	0.14↓	25.48%	7.18↓	1.97↓
Average layoff (EU)	1.221%	1.221%	–	–	1.211%	0.82↓	0.01↓
Unemployment rate	4.26%	4.28%	0.47↑	0.02↑	4.54%	6.57↑	0.28↑
Aggregate output	0.94572	0.94551	0.022↓		0.94306	0.28↓	
Average wage	0.9672	0.96724	0.0041↑		0.96823	0.11↑	

Table 7
Robustness: Higher risk aversion ($\sigma = 3$).

	Baseline	↑ 5%	Change (%)	Percentag point difference
Average effort	0.34634	0.34785	0.44↑	–
Average hiring rate (UE)	28.50%	27.39%	3.89↓	1.11↓
Average layoff (EU)	1.034%	1.029%	0.484↓	0.005↓
Unemployment rate	3.50%	3.62%	3.43↑	0.12↑
Aggregate output	0.955	0.95385	0.12↓	–
Average wage	0.96935	0.97028	0.1↑	–

5. Conclusion

This paper studies the effect of minimum wage on workers' on-the-job effort and resulting labor market consequences. The model incorporated employed workers' unobservable effort and firm contracting decisions into a search and matching model. This paper has two main contributions to the literature. First, this paper quantitatively shows that a higher minimum wage can motivate workers to work harder and therefore contribute to higher labor productivity. In other words, a higher minimum wage may improve the quality of the labor supply. By comparing the results from the model with workers' effort decisions with those from the model without workers' effort decisions, this paper suggests that workers' on-the-job effort has moderate offsetting effects on the cost of the higher minimum wage. Second, this paper shows that the "spillover effect" of the minimum wage can arise from the workers and the firms' incentive decisions. We view our approach as complementary to explanations of the "spillover effect" that focuses on the role of the relative price of labor. For example, our explanation of the existence of the "spillover effect" could also result in the change of the relative labor price across different types of workers. In this paper, however, we assume that workers are *ex-ante* homogeneous in order to focus on the interactions between incentive decisions and labor market conditions.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

A. *The hiring and layoff rates*

To calculate the hiring and layoff rates, we follow the process outlined in Shimer (2012) as closely as possible. We first download the basic monthly CPS files available at the NBER website https://data.nber.org/cps/. We matched the data using the Stata files provided at http://home.uchicago.edu/shimer/data/flows/. We then modify the files provided by Shimer (2012) to capture transitions between employers. We use the CPS data for September 1997 to December 2006 because the statutory minimum wage in the U.S. remained unchanged ($5.15) over this period. Considering another window of the years (2000–2011) had little effect on the measured transition rates.

B. *The unemployment rate*

To calculate the unemployment rate, we use the CPS data from September 1997 to December 2006. We first download the basic monthly CPS files available at the NBER website https://data.nber.org/cps/. We matched the data using the Stata files pro-vided at http://home.uchicago.edu/shimer/data/flows/. We then follow Shimer (2012) to identify the unemployed workers from the labor force status and calculate the average unemployment rate.

C. *The share of minimum wage workers*

To calculate the share of minimum wage workers, we first download CPS Merged Outgoing Rotation Groups. The data files are available online at http://www.nber.org/data/morg.html. We then calculate the number of workers that earn at and below the prevailing Federal minimum wage. The share of the minimum wage workers is the ration of the number of workers that earn at and below the prevailing Federal minimum wage over the number of total workers.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.econmod.2020.03.012.

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