GCOE Discussion Paper Series

Global COE Program

Human Behavior and Socioeconomic Dynamics

Discussion Paper No.129

Unemployment and Workplace Safety in a Search and Matching Model

Masaru Sasaki

April 2010

GCOE Secretariat
Graduate School of Economics
OSAKA UNIVERSITY
1-7 Machikaneyama, Toyonaka, Osaka, 560-0043, Japan

Unemployment and Workplace Safety in a Search and Matching Model*

Masaru Sasaki†

April 2, 2010

Abstract

Are recessions really good for workplace safety? This paper develops a model with search to consider the determinants of workplace safety and then investigates the relationship between unemployment and the incidence of work-related injury. There is a view following Arai and Thoursie (2005), Ruhm (2000) and Boone and van Ours (2006) that the rate of work-related injury is procyclical. However, data from several countries do not necessarily support this view. This paper considers an alternative approach to support the countercyclical variation in the rate of work-related injury in which the firm bargains about the optimal input for workplace safety.

JLE Classifications: J64, J65, J81

Keywords: Job Search, Workplace Safety, Work-Related Injury and Illness, Unemployment

*The author is grateful to the participants in Search Conference at Osaka University, FESAM2008 and the 2009 EALE Annual Meeting. I also thank seminar participants in the Kansai Labor Seminar, Nihon University , GRIPS, and Tohoku University. Part of this research is financially supported by the Japan Society for the Promotion of Science, No. 20530196. All errors are mine.

†Institute of Social and Economic Research, Osaka University, 6-1 Mihogaoka, Ibaraki, Osaka, 567-0047, Tel: +81-6-6879-8560, Fax: +81-6-6878-2766, E-mail: sasaki@econ.osaka-u.ac.jp.

1 Introduction

Are recessions really good for workplace safety? This paper develops a model with search to consider the determinants of workplace safety and to explore the relationship between unemployment and the incidence of work-related injury. Assuming that the probability of a worker being injured in a workplace depends negatively on the amount of input for workplace safety purchased by firms, there is a trade-off for firms between the cost of the input and the risk of losing a worker.

There is a view that the rate of workplace injury is procyclical, thereby indicating that workplaces are safer during recessions. For instance, Arai and Thoursie (2005) argue that during an economic boom when labor demand exceeds labor supply, firms hired even inexperienced workers. These were more likely to be injured in the workplace, and therefore both employment and the flow of employed workers absent because of work-related injuries were higher during economic upturns. Put differently, employment and work-related injuries are lower during recessions. Therefore, the unemployment rate and the flow rate of absent employed workers are *negatively* correlated after controlling for the labor force.

Further, Ruhm (2000) shows that the mortality rate was also procyclical, indicating that people were healthier during recessions. He argued that workers' health was sapped by the deterioration of working conditions, increased workload and work-related stress caused by longer working hours during a short-lasting economic boom. Boone and van Ours (2006) also suggest that the rate of work-related injury was procyclical, but provided an alternative explanation to Ruhm (2000) as follows. Consider the situation where the extent of injury incurred by a worker is asymmetric; that is, an employer cannot observe the worker's injury. The worker is then less likely to report his or her accident and attempt to keep working during a recession when unemployment is high if he or she believes that workers who report accidents and take sick leave are more likely to be fired by the employer. Hence, even though working conditions remain unchanged irrespective of the business cycle, the rate of work-related injury is lower during recessions.

However, there is an opposing view that the rate of work-related injury is not necessarily procyclical. For example, Ussif (2004) undertook an international comparative study using time-series data between 1970 and 1999 from several countries and found the opposite relationship; that is, as employment size increased, the number of work-related injuries decreased. In other words, the unemployment rate and the flow rate of absent employed workers are *positively* correlated after controlling for the labor force. Additionally, Ussif (2004) found that these rates move in the same direction after controlling for any time trend. On this basis, Ussif (2004) concludes that the number of work-related injuries declined because of technical advancement in workplace devices and the environment as captured by the time trend.

To the best of my knowledge, we have not so far considered other elements determining the number of injuries in the workplace, even though it is obviously of great importance from the policymakers' point of view. Many other factors affect the rate of work-related injury, including employer practices at the workplace, employee training, the role of unions, and the provision of safety mandates. This paper focuses attention on the determinants of the level of workplace safety and develops a model that endogenizes the probability of a worker being subject to a work-related injury. In this model, the firm bargains on how much input to purchase for workplace safety with its worker. We then explore the optimal safety level that determines the number of injuries at the workplace in response to exogenous shocks. Our contribution is to provide an alternative approach to explain the relationship between the unemployment rate and the incidence of work-related injury by incorporating the determinants of the input for workplace safety into a search and matching model. However, this paper does not discuss the role of mandates in keeping workplaces safe by, for example, the Occupational Safety and Health Administration (OSHA) in the US and its effect on labor market conditions.[1]

There are already a few theoretical studies in this field. For example, Engström and Holmlund (2007) construct a general equilibrium model with search by incorporating absenteeism from work as an additional state.[2] They derived the optimal compensation

[1] Jolls (2008) surveys both theoretical and empirical studies on the effects of OSHA and the compensation programs for work-related injuries.

[2] Barmby et al. (1994) presents a model in which the wage is endogenously determined within an efficiency wage setting. They show that the wage is adjusted to affect the decision on absence from

package to maximize the expected profit affected by the number of job applications and the determinants of absenteeism of sick workers from work under the condition that accidents randomly took place. They also provide a welfare analysis and compared alternative social insurance policies. They focus on the individual worker's decision on labor supply and sickness absenteeism. Instead, our paper focuses on the determinants of the amount of input purchased by *firms* for workplace safety to reduce the risk of losing employed workers from work-related injuries.

Alternatively, using time series data from 16 OECD countries, Boone and van Ours (2006) present empirical evidence that the procyclical variations in workplace accidents are more attributable to a reluctance to report accidents during recessions than to changes in working conditions and the composition of experienced and inexperienced workers. Other empirical studies in this area have thus far explored the effect of OSHA on work-related injuries using state-, industry-, and plant-level data from the US.[3] Overall, the effect of OSHA enforcement on the rate of work-related injury was found to be modest (Viscusi 1979 1986, Bartel and Thomas 1985). In contrast, Scholz and Gray (1990) found a significant relationship between OSHA enforcement and the rate of work-related injury using plant-level data of firms that were frequently inspected. According to a recent study by Mendeloff (2005), this significant relationship was still observed in the early 1990s but disappeared thereafter.

Our findings are summarized as follows. To start with, productivity improvement encourages firms to enter the labor market, which makes it more competitive for firms to hire workers. An increase in competitiveness among firms then lowers the marginal gain of operating an actively occupied position and its marginal cost with respect to the level of safety, and the latter effect overwhelms the former in an environment where both the wage and the amount of input for workplace safety are bargained over. Therefore, firms have an incentive to improve safety conditions in the workplace. In addition, the productivity improvement leads to an increase in profit, which implies an increase in

sickness. Garibaldi and Wasmer (2005) also construct a multistage model where the wage is endogenously determined.

[3] Smith (1992) surveyed these empirical studies in the early 1990s.

the opportunity cost that firms would have incurred if their workers had been injured. Firms are then induced to purchase more input for workplace safety to reduce the risk of work-related injury. Overall, the productivity improvement unambiguously raises the amount of input used for workplace safety. The risk of work-related injury that depends negatively on the input for workplace safety is then countercyclical.

Considering the impact on the unemployment rate, the productivity improvement encourages firm entry, which increases the tightness of the labor market and thereby lowers the rate of unemployment. An increase in the amount of input for workplace safety then increases active employment but reduces absenteeism. The flow rate to the unemployment pool is then larger from the active employment pool but smaller from the absenteeism pool. We find that the latter effect exceeds the former, and therefore an increase in the input for workplace safety lowers the unemployment rate. The overall effect of the productivity improvement is then negative on the unemployment rate, and this is consistent with the implications found in the extant literature. Our model of the determinants of workplace safety then shows that both the risk of work-related injury and the unemployment rate are countercyclical, and this contrasts with the findings in Arai and Thoursie (2005), Ruhm (2000), and Boone and van Ours (2006), but is consistent with Ussif (2004). We also considers the model in which the cyclical shock arrives at the economy according to the Poisson process and obtain the same implication derived from the steady state equilibrium model.

We then extend the model to analyze the effects of several policy parameters (namely, sickness and unemployment benefits). Among these, the effect of unemployment benefits is particularly noteworthy. To the best of our knowledge, unemployment benefits and workplace safety have thus far been discussed separately, and we show that a strong policy linkage exists between them. Namely, an increase in unemployment benefits discourages firms from entering the labor market, which makes it less competitive for firms to hire workers. An increase in the unemployment benefit then raises wages and lowers profits, implying a decrease in the opportunity cost firms would have incurred if their workers had been injured. These firms are then less concerned about reducing the risk of work-related injury. Put differently, an increase in unemployment benefits raises the value of unemployment, which makes the state of unemployment more favorable for workers. To attract unemployed workers, firms raise the expected value of employment for an active worker and for an absent worker by reducing the risk of losing the wage because of work-related injury. Firms are therefore encouraged to increase the input for workplace safety. The overall impact of unemployment benefits is then unambiguous on the risk of work-related injury. However, if the final effect is dominant, we can conclude that unemployment benefits are a valid tool to reduce the risk of injury in the workplace.

The organization of the rest of this paper is as follows. Section 2 illustrates the empirical data. Section 3 presents a matching model with an endogenous input determinant for workplace safety. Section 4 provides comparative statics exercises and discusses the determinants of the relationship between unemployment and the incidence of work-related injury through a productivity improvement. The effects of sickness and unemployment benefits are analyzed in Section 5. We discuss several miscellaneous issues in Section 6, and the final section provides some concluding remarks.

2 Graphical Inspection

In this section, we show the empirical relationships existing between the rate of unemployment and the rate of work-related injury. For visual inspection, we compare the relative variations in the unemployment rate and the rate of nonfatal injury. Figure 1 displays the annual growth rates of these variables using time-series data for selected countries in Europe, North America, and Asia. The data are from LABORSTA, the International Labour Office (ILO) database on labor statistics. Based on this data, it appears that a negative relationship between the unemployment rate and the rate of nonfatal injury exists in Poland, Romania, Spain, Sweden, Canada, and the US. These data then support the view of Arai and Thoursie (2005), Ruhm (2000), and Boone and van Ours (2006) that while the unemployment rate is countercyclical, the injury rate is procyclical because inexperienced workers (who are more likely to be hired during an economic boom) are more likely to be injured in the workplace. However, we cannot discern a clear negative relationship in the other sample countries and, in fact, there is a positive relationship during some subperiods. For example, in Italy both the unemployment rate and the nonfatal injury rate decline in the 2000s, while in the UK both have moved in the same direction since the late 1990s. In Japan, both the unemployment rate and the nonfatal injury rate have also moved in the same direction during the period of the bubble economy (the late 1980s and the early 1990s) and again after 2005.

This evidence helps illustrate that there are many other mechanisms or factors that determine the relationship between the unemployment rate and the injury rate. We choose to focus attention on the labor demand side through the firm's optimal choice of input for workplace safety to prevent accidents from occurring.

3 The Model

3.1 Steady States

We consider a continuous-time model with matching in which there are a continuum of risk neutral workers and a continuum of risk neutral firms. The measure of workers is normalized to one. Workers are infinitely lived and homogeneous with respect to their preferences for work. At any point in time, a worker is either employed or nonemployed. In turn, there are two states of employment: an active working state and an absent state because of work-related injury. Nonemployment meanwhile consists of an unemployment state in which workers actively search for a job and a nonlabor participation state in which injured workers recuperate at home and thus cannot engage in job search. The injured workers in the absent state can automatically return to the same workplace once they are well, while those in the state of nonlabor force participation enter the unemployment pool and begin looking for a job after making a recovery.

An employed worker is injured in the workplace and is absent from work at a Poisson rate $\lambda(k)$, where k represents the safety and health input, with its price normalized to one, purchased by a firm to improve workplace safety conditions. To improve working conditions, firms usually incur legal welfare expenses to comply with labor standards and nonlegal welfare expenses for housing, food, and work uniforms along with the costs of sickness and injury. Work-related injuries are defined here as an immediate health hazard incurred during work that forces workers to be absent from work for treatment. They potentially include lower back pain, cuts, bruises, broken bones, falls, being struck by objects, mental illness, and so on, but not long-term latent health hazards from work such as pneumoconiosis. We assume that $\lambda(k)$ is characterized by $\lambda'(\cdot) < 0$, $\lambda''(\cdot) > 0$, $\lambda(0) = \overline{\lambda} \leq \infty$ and $\lim_{k\to\infty} \lambda(k) = \underline{\lambda} \geq 0$. As a firm buys input to improve workplace safety conditions, the likelihood that an employed worker is injured is reduced at a decreasing rate. The absent employed worker heals and immediately returns at the same workplace at an exogenous Poisson rate α.[4] We thus assume that k affects the accident rate in the workplace but not the extent or duration of injury.

There is search and matching friction. The unemployed and job vacancies are matched randomly according to a matching function, $m(u, v)$ where u is the number of unemployed and v is a measure of job vacancies across all firms. The matching function is assumed to exhibit constant returns-to-scale, implying that the rate at which a vacancy encounters an unemployed worker is computed by $m(u, v)/v = m(u/v, 1) \equiv q(\theta)$ where $\theta \equiv v/u$ is the tightness of the labor market, while the rate at which an unemployed worker matches with a job vacancy is represented by $\theta q(\theta)$. Note that $q(\theta)$ is decreasing in θ; that is, $q'(\theta) < 0$.

A job is separated at an exogenous Poisson rate δ, regardless of whether an employed worker actively works or is absent from work. While the active worker then becomes unemployed and begins to search for a job, the absent worker loses his or her employment status and is removed from the labor force because of the treatment of injury. We assume that in a similar manner as the absent employed worker, nonlabor participants get well again at the exogenous Poisson rate α.

[4] In fact, the rate of return to work is not exogenous as it largely depends on the amount of compensation as well as the extent of the injury or illness. Unfortunately, it is difficult to observe whether absent workers heal from their injuries or get well from sickness. Meyer, Viscusi, and Durbin (1995) undertook a natural experiment and found that an increase in the compensation received by absent employed workers extended the duration of absence. Similar results are obtained in Ehrenberg (1988) and Krueger (1990).

Both workers and firms discount the future at the common rate r. Before various value functions are developed, the timing of decisions needs to be defined. We assume that a firm recruits a worker and then simultaneously bargains over both the wage and the amount of input for workplace safety k with the worker. In this setup, the wage and the amount of input are not the predetermined variables, being allowed to instantaneously change in response to exogenous shifts. Different timings of the decisions and different ways of decision making on the wage and the input for workplace safety are possible, which we discuss later.

We begin with the value for an employed worker of engaging actively in work as follows:

$$rW = w + \lambda(k)(W_a - W) + \delta(U - W). \tag{1}$$

The instantaneous utility is linear with earnings. The second term on the right-hand side of eq.(1) represents the expected capital loss incurred by being injured, and the third term indicates the expected capital loss of being unemployed. We assume that a newly injured worker does not choose to quit a job to be out of labor force participation; that is, $W_a \geq N$, the condition to meet hereinafter described. In a similar manner, the value for an employed worker of being absent from work because of work-related injury is defined by:

$$rW_a = \alpha(W - W_a) + \delta(N - W_a). \tag{2}$$

We assume in the benchmark case that if absent from work because of injury in the workplace, the worker is not recompensed at all for his or her earnings w. Note that the disutility incurred by the absent employed worker is ruled out in this model without loss of generality. The first term on the right-hand side shows the expected capital gain of making a recovery, and the second is the expected capital loss of losing the status of employment at δ, where N represents the value of being out of the labor force because of the treatment of injury.

The value of unemployment is as usual given by:

$$rU = \theta q(\theta)(W - U). \tag{3}$$

At any point in time, an unemployed worker who is assumed to receive no instantaneous utility meets a firm with a vacant job at the transition rate $\theta q(\theta)$. The value of being out of the labor force is:

$$rN = \alpha(U - N). \tag{4}$$

A nonlabor force participant heals at rate α and becomes unemployed, and is then looking for a job.

The difference between eqs.(1) and (2) is given by:

$$W - W_a = \frac{w + \delta(U - N)}{r + \alpha + \delta + \lambda(k)}.$$

This shows that active employment is more favorable for the worker than absenteeism from work as a result of work-related injury because the absent worker is not compensated and is more likely to be out of the labor force.

Substituting this above equation and eqs.(4) into eq.(1) yields the worker's surplus:

$$W - U = \frac{r + \alpha + \delta}{(r + \delta)(r + \alpha + \delta + \lambda(k))}\left[w - \frac{r + \alpha + \lambda(k)}{r + \alpha} rU\right]. \tag{5}$$

We assume $W \geq U$ and therefore obtain:

$$w \geq \frac{r + \alpha + \lambda(k)}{r + \alpha} rU.$$

The wage has to equal or exceed the reservation wage (rU) plus the expected injury risk premium ($\frac{\lambda(k)}{r+\alpha} rU$). In a similar manner, we obtain:

$$W_a - N = \frac{\alpha}{(r + \delta)(r + \alpha + \delta + \lambda(k))}\left[w - \frac{r + \alpha + \lambda(k)}{r + \alpha} rU\right].$$

The optimal choice for a newly injured worker is to stay employed but not quit the current job, again if the wage is large enough to satisfy $w \geq \frac{r+\alpha+\lambda(k)}{r+\alpha} rU$.

Next, we discuss the value functions for a firm. We consider a firm to be a collection of individual jobs. At any point in time, jobs are either occupied, unfilled, or inactive because employed workers are absent as a result of work-related injuries. We assume that firms operate under a constant returns-to-scale production technology with respect to the labor input. This assumption ensures that jobs in the firm are independent of one another.

The value of a job being actively occupied is:

$$rJ = p - w - k + \lambda(k)(J_a - J) + \delta(V - J). \tag{6}$$

A matched pair produces p instantaneously. The second term on the right-hand side of eq.(6) represents the expected capital loss of a job being inactive because a worker is absent from work owing to a work-related injury. The third term indicates the expected capital loss of a job being separated.

Similarly, the value of an occupied job being inactive because of work-related injury is:

$$rJ_a = \alpha(J - J_a) + \delta(V - J_a). \tag{7}$$

The job turns out to be active at rate α and separated at rate δ. We assume for simplicity that there are no disability insurance programs. However, in reality many firms join federal or state disability insurance programs with compulsory payroll deductions. If their own employees are then injured in the workplace, they are compensated through their program. Because the disability insurance program is mainly financed by firms, we suggest that firms indirectly bear the burden of compensation. Further, because premiums depend positively on their safety record, these firms have an incentive to improve workplace conditions, which is different from our motivation in the sense that firms are encouraged to improve workplace conditions to reduce the likelihood that workplace accidents cause a fall behind in production. Furthermore, many firms have their own absence leave programs with payment. According to a survey conducted by the Japanese Ministry of Health, Labour and Welfare (MHLW) in January 2008, 58.6% of the surveyed firms have their own absence leave programs and 41.1% keep paying an average 85.8–93.6% of salaries to absent employees. For the surveyed firms with more than 1,000 employees, 85.3% have their own absence leave programs and 56.8% pay 88.5–91.8% of their salaries to absent workers.[5]

The value of a vacancy is given as usual by:

$$rV = -\phi + q(\theta)(J - V). \tag{8}$$

A vacancy is incurred the instantaneous cost ϕ and filled at the transition rate $q(\theta)$. The free-entry condition ensures $V = 0$ in equilibrium.

Eqs.(6) and (7) give the following equations:

$$J = \frac{(r + \alpha + \delta)(p - w - k)}{(r + \delta)(r + \alpha + \delta + \lambda(k))} \geq 0, \tag{9}$$

and

$$J_a = \frac{\delta(p - w - k)}{(r + \delta)(r + \alpha + \delta + \lambda(k))} \geq 0.$$

$J_a \geq V = 0$ if the instantaneous profit equals or exceeds zero, so the inactive firm does not choose to fire the absent worker.

A firm and a worker consummate a match if and only if the joint surplus gained through this match is nonnegative, and then the wage and the amount of k are simultaneously chosen to maximize the weighted product of the net return from the job match according to the Nash bargaining rule. Assuming that the worker's share of the surplus is defined by $\beta \in [0, 1]$, the conditions to determine w and k are given by:

$$(1 - \beta)(W - U) = \beta J, \tag{10}$$

[5] See *Rodo Sinbun* (Labour Newspaper) No. 2688 (July 14, 2008) in Japanese published by *Rodo Sinbunsha*.

and

$$(1-\beta)(W-U)\left(\frac{\partial J}{\partial k}\right)=-\beta J\left(\frac{\partial(W-U)}{\partial k}\right). \tag{11}$$

Substituting eqs.(5) and (9) into eq.(10) gives:

$$w=\beta(p-k)+(1-\beta)\left[\frac{r+\alpha+\lambda(k)}{r+\alpha}\right]rU.$$

The wage is determined by the weighted-average of the instantaneous net production and the reservation wage rU, after accounting for the risk of injury. From eqs.(3), (8), and (10), the reservation wage rU can be expressed as $rU=\frac{\beta}{1-\beta}\phi\theta$. Substituting this into the above wage equation yields:

$$w=\beta\left[p-k+\frac{r+\alpha+\lambda(k)}{r+\alpha}\phi\theta\right]. \tag{12}$$

The wage depends negatively on k. An increase in k lowers the risk of injury in the workplace, which means that it is more favorable for the worker to be employed than unemployed. This reduces the worker's bargaining position, as directly resulting in a lower wage. In addition, an increase in k lowers expected profit, leading to a further decrease in the wage. Recall that $w\geq\frac{r+\alpha+\lambda(k)}{r+\alpha}rU$ to ensure $W\geq U$ and $W_a\geq N$. We thus have:

$$\theta\leq\frac{(1-\beta)(r+\alpha)(p-k)}{\beta(r+\alpha+\lambda(k))\phi}.$$

The term on the right-hand side either increases or decreases with k. If labor market tightness is lower than the right-hand side term, conditions such as $W\geq U$ and $W_a\geq N$ are satisfied.

The problem regarding the Nash bargaining determination over the input for workplace safety is solved in a similar manner. Using eqs.(5), (9) and (12), eq.(11) can be rewritten as:

$$-\frac{\lambda'(k)}{r+\alpha+\delta+\lambda(k)}\left[(1-\beta)(p-k)-\beta\frac{r+\alpha+\lambda(k)}{r+\alpha}\phi\theta\right]=1+\beta\left(-1+\frac{\lambda'(k)}{r+\alpha}\phi\theta\right). \tag{13}$$

The term on the left-hand side represents the marginal gain of operating an actively occupied job with respect to the input for workplace safety while the term on the right-hand side is its marginal cost. The parentheses in the marginal gain term represent the instantaneous profit $(p-w-k)$,which is assumed to be zero or positive for all k. Using eq.(12), the condition $p-w-k \geq 0$ is rewritten as:

$$\theta \leq \frac{(1-\beta)(r+\alpha)(p-k)}{\beta(r+\alpha+\lambda(k))\phi}.$$

This condition coincides with that needed to ensure $W \geq U$ and $W_a \geq N$. The left-hand side of eq.(13) is positive, as must be the right-hand side. The marginal cost consists of the direct cost of k with its price normalized to one plus the marginal wage cut with respect to k, implying $\partial w/\partial k(<0)$. The marginal gain is decreasing with k while the marginal cost is increasing in k. The second-order condition ensures that the optimal amount of input maximizes the weighted product of the net return from the job match.

Eq.(13) is depicted as an upward sloping curve in $k-\theta$ space. Here, a higher θ lowers the marginal gain, shifting the curve to the left and therefore lowering k. Meanwhile, a higher θ shifts the marginal cost curve to the right, thereby increasing k. We recognize that the latter effect dominates the former because both w and k are simultaneously bargained. k is then determined through the Nash bargaining rule, taking into account the effect of k on w.

Substituting eq.(9) into eq.(8) yields the free-entry condition:

$$\frac{q(\theta)(r+\alpha+\delta)}{(r+\delta)(r+\alpha+\delta+\lambda(k))}\left[(1-\beta)(p-k)-\beta\frac{r+\alpha+\lambda(k)}{r+\alpha}\phi\theta\right]=\phi. \tag{14}$$

Eq.(14) is represented as a horizontal line in $k-\theta$ space; that is, θ is constant irrespective of k because the partial differential of the left-hand side with respect to k turns out to be zero according to eq.(13). An increase in k lowers $\lambda(k)$ and thereby the likelihood that a worker is injured in the workplace, which induces firms to enter the market. However, an increase in k simultaneously raises the costs of operation, which eventually negates the effect on entry at the optimal level. Both eqs.(13) and (14) are shown in Figure 2.

We next illustrate the steady-state conditions needed to derive the unemployment rate and the fraction of absent employed workers. Let u be the fraction of unemployed workers, and a and n denote the fraction of employed workers who are absent from work and the fraction of nonlabor force participants who cannot search for a job because of the treatment of injury, respectively. The remainder is then considered active employed. The steady-state conditions require:

$$\begin{aligned} \theta q(\theta)u &= \delta(1-u-a-n)+\alpha n, \\ \alpha n &= \delta a, \\ \text{and } (\alpha+\delta)a &= \lambda(k)(1-u-a-n). \end{aligned}$$

Then, we obtain:

$$\begin{aligned} u &= \frac{\delta(1-\delta)\lambda(k)}{(\alpha+\delta)(\alpha+\lambda(k))(\delta+\theta q(\theta))+\delta(1-\delta)\lambda(k)}, \\ a &= \frac{\alpha\lambda(k)(\delta+\theta q(\theta))}{(\alpha+\delta)(\alpha+\lambda(k))(\delta+\theta q(\theta))+\delta(1-\delta)\lambda(k)}, \\ \text{and } n &= \frac{\delta\lambda(k)(\delta+\theta q(\theta))}{(\alpha+\delta)(\alpha+\lambda(k))(\delta+\theta q(\theta))+\delta(1-\delta)\lambda(k)}. \end{aligned} \tag{15}$$

The fraction of employed workers who are actively engaged in work is therefore computed by:

$$e \equiv 1-u-a-n = \frac{\alpha(\alpha+\delta)(\delta+\theta q(\theta))}{(\alpha+\delta)(\alpha+\lambda(k))(\delta+\theta q(\theta))+\delta(1-\delta)\lambda(k)}. \tag{16}$$

As one would expect, greater labor market tightness θ lowers the fraction of unemployed workers u but raises both a and n because the measure of employed e is larger in size. An increase in the input for workplace safety k lowers both a and n because workplace safety conditions are improved. An increase in k raises u through the channel of an increase in e, but on the other hand, lowers u through the channel of a decrease in n. Overall, the latter effect dominates the former: that is, an increase in k lowers u.

The unemployment rate is then computed by:

$$\widetilde{u} \equiv \frac{u}{1-n} = \frac{\delta(1-\delta)\lambda(k)}{\alpha(\alpha+\delta+\lambda(k))(\delta+\theta q(\theta))+\delta(1-\delta)\lambda(k)}.$$

Similar to u, the unemployment rate depends negatively on k and θ.

Eqs.(13), (14) and (15) provide a complete description of the equilibrium used to solve for the vector (k, θ, u, a, n). For convenience, these equilibrium conditions are summarized below.

(i) Condition to determine k (rewritten version of eq.(13))

$$-\frac{\beta\lambda'(k)\delta\phi\theta}{r+\alpha} = (1-\beta)[\lambda'(k)(p-k)+(r+\alpha+\delta+\lambda(k))]$$

(ii) Free-entry condition (eq.(14))

$$\frac{q(\theta)(r+\alpha+\delta)}{(r+\delta)(r+\alpha+\delta+\lambda(k))}\left[(1-\beta)(p-k)-\beta\frac{r+\alpha+\lambda(k)}{r+\alpha}\phi\theta\right] = \phi$$

(iii) Steady-state conditions (eq.(15))

$$\begin{aligned} u &= \frac{\delta(1-\delta)\lambda(k)}{(\alpha+\delta)(\alpha+\lambda(k))(\delta+\theta q(\theta))+\delta(1-\delta)\lambda(k)} \\ a &= \frac{\alpha\lambda(k)(\delta+\theta q(\theta))}{(\alpha+\delta)(\alpha+\lambda(k))(\delta+\theta q(\theta))+\delta(1-\delta)\lambda(k)} \\ \text{and } n &= \frac{\delta\lambda(k)(\delta+\theta q(\theta))}{(\alpha+\delta)(\alpha+\lambda(k))(\delta+\theta q(\theta))+\delta(1-\delta)\lambda(k)} \end{aligned}$$

Eq.(13) is upward sloping while eq.(14) is horizontal in $k-\theta$ space. These two equations ensure the existence of a unique equilibrium for k and θ, and then it is possible to find the optimal value set (u, a, n) from eq.(15). We investigate the characterizations of the equilibrium by examining the comparative statics in the following section.

Our focus is on the relationship between the unemployment rate and the incidence of work-related injury via exogenous parameter changes. The main purpose is to illustrate the changes in workplace safety and labor market conditions in response to a productivity improvement. We here focus on the steady-state equilibrium, not the equilibrium where the aggregate productivity shock is anticipated (Mortensen and Pissarides 1994), which is considered latter. Using (i) first-order conditions and (ii) free-entry conditions, the comparative statics system is described. The appendix provides analytical detail.

Proposition 1 *The comparative statics analysis provides the following characterizations: (1) an increase in productivity raises both the amount of input for workplace safety and labor market tightness:*

$$\frac{dk}{dp} > 0, \ \ \textit{and} \ \frac{d\theta}{dp} > 0,$$

(2) an increase in productivity lowers the unemployment rate $(\widetilde{u})$*:*

$$\frac{d\widetilde{u}}{dp} = \underbrace{\left(\frac{\partial \widetilde{u}}{\partial k}\right)}_{-}\underbrace{\left(\frac{dk}{dp}\right)}_{+} + \underbrace{\left(\frac{\partial \widetilde{u}}{\partial \theta}\right)}_{-}\underbrace{\left(\frac{d\theta}{dp}\right)}_{+} < 0,$$

and (3) an increase in productivity raises the employment rate (e) *but exerts an ambiguous effect on the fractions of absent workers* (a) *and nonlabor force participants* (n)*:*

$$\begin{aligned}
\frac{da}{dp} &= \underbrace{\left(\frac{\partial a}{\partial k}\right)}_{-}\underbrace{\left(\frac{dk}{dp}\right)}_{+} + \underbrace{\left(\frac{\partial a}{\partial \theta}\right)}_{+}\underbrace{\left(\frac{d\theta}{dp}\right)}_{+} \lesseqgtr 0, \\
\frac{dn}{dp} &= \underbrace{\left(\frac{\partial n}{\partial k}\right)}_{-}\underbrace{\left(\frac{dk}{dp}\right)}_{+} + \underbrace{\left(\frac{\partial n}{\partial \theta}\right)}_{+}\underbrace{\left(\frac{d\theta}{dp}\right)}_{+} 0 \lesseqgtr 0, \\
\frac{de}{dp} &= \underbrace{\left(\frac{\partial e}{\partial k}\right)}_{+}\underbrace{\left(\frac{dk}{dp}\right)}_{+} + \underbrace{\left(\frac{\partial e}{\partial \theta}\right)}_{+}\underbrace{\left(\frac{d\theta}{dp}\right)}_{+} > 0.
\end{aligned}$$

As depicted in Figure 3, an increase in productivity p shifts eq. (13) to the right and eq. (14) upward, thus leading to unambiguous increases in k and θ. More firms enter the labor market and create vacancies because the productivity improvement leads to an increase in profit, thus resulting in an increase in θ. As shown in eq. (13), an increase in θ lowers the marginal gain in operating an actively occupied job and the marginal cost with respect to k, the latter effect overwhelms the former, and therefore firms have an incentive to increase the amount of input for workplace safety. Additionally, an increase in productivity p directly raises the marginal gain, implying an increase in the profit that firms would have earned without worker absenteeism. An increase in the opportunity cost incurred by forcing the worker to be absent induces the firms to increase the amount of input for workplace safety k to prevent employed workers from being injured in the workplace, leading to a lower rate of injury $\lambda(k)$. When combined with the above effects, the productivity improvement unambiguously exerts a positive impact on the input of workplace safety k.

We recognize that an increase in productivity lowers the unemployment rate through the channels of the increased amount of input for workplace safety k and greater tightness in the labor market θ. These results imply that both the unemployment rate and the rate of injury in the workplace are countercyclical. This view differs from Arai and Thoursie (2005), Ruhm (2000), and Boone and van Ours (2006), but supports Ussif (2004), who shows that despite a steady increase in the number of employed workers, the number of work-related injuries declined from 1970 to 1999 using time-series data from selected countries. That is, he implied a *positive* relationship between the unemployment rate and the rate of injury in the workplace. Our findings are then at least partially consistent with data from some countries, including Italy, the UK, and Japan, as displayed in Figure 1.

Productivity improvement provides ambiguous effects on the fractions of absent workers (a) and nonlabor force participants (n). An increase in k reduces the flow of absent workers from e to a, but on the other hand, greater labor market tightness increases employment e, which thereby leads to an increasing flow of absent workers from e to a, even though the rate of injury $\lambda(k)$ remains fixed. The same intuition can be applied in the case of n.

The following exercise explores the effect of the healing rate α on labor market conditions and helps illuminate differences in the rate of injury by occupational type.

Proposition 2 *The comparative statics analysis provides the following characterizations: (1) The higher rate of healing α increases labor market tightness but has an ambiguous effect on the amount of input for workplace safety; that is:*

$$\frac{dk}{d\alpha} \lesseqgtr 0, \ \ \textit{and} \ \frac{d\theta}{d\alpha} > 0,$$

(2) an increase in the healing rate either raises or lowers the unemployment rate ($\widetilde{u}$):

$$\frac{d\widetilde{u}}{d\alpha} = \underbrace{\left(\frac{\partial \widetilde{u}}{\partial k}\right)}_{-}\underbrace{\left(\frac{dk}{d\alpha}\right)}_{+/-} + \underbrace{\left(\frac{\partial \widetilde{u}}{\partial \theta}\right)}_{-}\underbrace{\left(\frac{d\theta}{d\alpha}\right)}_{+} \lesseqgtr 0.$$

As the healing rate is higher, that is, workers are not seriously injured and can return to work sooner, more firms enter the market and create vacancies because the loss that the firm would incur by their own workers' absenteeism is relatively small. Therefore, eq.(14) shifts upwards. This implies that jobs are more likely to be created in sectors in which workers' injuries are generally not severe, such as the retail sales and services sectors. In contrast, firms are discouraged from creating jobs in sectors where the extent of work-related injury is usually severe, such as construction, transportation, and mining.

The higher healing rate has an ambiguous effect on the amount of input for workplace safety k. Because eq.(14) is shifted up, the higher θ by firm entry induces firms to purchase more input for workplace safety k according to eq.(13). In addition, the higher healing rate shifts eq.(13) to the left, leading directly to a decrease in k. If injured workers can return to work sooner, work-related injury is a trivial issue; firms do not have an incentive to buy input k to prevent accidents from occurring in the workplace. On the other hand, the higher healing rate raises the values of employment, $W(w)$ and $W_a(w)$. This means that the employment state is more attractive for the unemployed than the state of unemployment, thus lowering the reservation wage and thereby the wage. This increases the marginal gain and shifts the curve to the right, and firms are therefore encouraged to purchase input for workplace safety k. As shown in Figure 4, we conclude that the amount of input for workplace safety and the healing rate are not monotonically correlated, so firms do not necessarily practice to keep workplaces safe by purchasing k in sectors with lower healing rates α where the extent of work-related injury is severe.

3.2 Cyclical Changes

The previous section has shown the effects of productivity on the labor market at the steady states, and therefore it did not allow for the cyclical implications of productivity change. To capture the characterizations of cyclical productivity shocks, the model is extended to the case in which productivity shock arrives according to the Poisson process in this section. Productivity takes either a high value p_h during an economic boom or a low value p_l during a recession at a Poisson rate σ. Incorporating this Poisson rate into the model allows the economy to switch back and forth between economic boom and recession probabilistically. We then compare the equilibrium when the economy is in a recession and when the economy is in an economic boom and explore the cyclical patterns of the rate of injury in the workplace and unemployment rate. Furthermore, we focus attention on the differences in terms of the relationship between the rate of injury in the workplace and the unemployment rate between the steady state equilibrium and the equilibrium of the model into which the cyclical productivity shock is incorporated.

The values for a worker in each state are rewritten as:

$$rW_i = w_i + \lambda(k_i)(W_{ai} - W_i) + \delta(U_i - W_i) + \sigma(W_j - W_i), \tag{17}$$

$$rW_{a_i} = \alpha(W_i - W_{a_i}) + \delta(N_i - W_{a_i}) + \sigma(W_{aj} - W_{ai}), \tag{18}$$

$$rN_i = \alpha(U_i - N_i) + \sigma(N_j - N_i), \tag{19}$$

and

$$rU_i = \theta_i q(\theta_i)(W_i - U_i) + \sigma(U_j - U_i) \text{ where } i, j = h, l,\ i \neq j. \tag{20}$$

The last terms on the right-hand side of the above equations represent the expected capital change of the value because of the arrival of the productivity shock.

In a similar manner, the values for a job in each state are given by:

$$rJ_i = p_i - w_i - k_i + \lambda(k_i)(J_{a_i} - J_i) - \delta J_i + \sigma(J_j - J_i), \tag{21}$$

and

$$rJ_{a_i} = \alpha(J_i - J_{a_i}) - \delta J_{a_i} + \sigma(J_{aj} - J_{ai}) \text{ where } i, j = h, l,\ i \neq j. \tag{22}$$

Because the free-entry condition ensures the value of a vacancy to be zero in equilibrium, we obtain:

$$\frac{\phi}{q(\theta_i)} = J_i. \tag{23}$$

Similarly to Section 3.1, a firm and a worker match if and only if the joint surplus gained through this match is nonnegative, and then the wage and k are simultaneously chosen to maximize the joint surplus according to the Nash bargaining rule. The condition to determine the wage is given by:

$$(1 - \beta)(W_i - U_i) = \beta J_i \text{ where } i = h, l. \tag{24}$$

For simplification of the computation, we assume that there exist only two amounts of the input for workplace safety, $\overline{k}$ and $\underline{k}$ ($\overline{k} > \underline{k}$), and a firm and a worker choose either of them to maximize the joint surplus of job match according to the following rule.

$$k_i = \begin{cases} \overline{k} \text{ if } (W_i(\overline{k}) - U_i)^{\beta} J_i(\overline{k})^{1-\beta} \geq (W_i(\underline{k}) - U_i)^{\beta} J_i(\underline{k})^{1-\beta}, \\ \underline{k} \text{ otherwise, where } i = h, l. \end{cases} \tag{25}$$

There are four possible patterns of the input for workplace safety: $(k_h, k_l) = (\overline{k}, \overline{k})$, $(\overline{k}, \underline{k})$, $(\underline{k}, \overline{k})$ and $(\underline{k}, \underline{k})$. We choose one of these patterns that satisfies with the equilibrium conditions, eq.(17) - eq.(25).

Because there are too many equilibrium conditions to solve for the variables analytically, we have to rely on the numerical analysis to compare the equilibrium variables between a recession and an economic boom. We employ two steps to solve for the model. The first step is to solve for 16 variables $\{W_h, W_{a_h}, N_h, U_h, J_h, J_{a_h}, w_h, \theta_h, W_l, W_{a_l}, N_l, U_l, J_l, J_{a_l}, w_l, \theta_l\}$ from eq.(17) - eq.(24) for each pattern of the input for the workplace safety. The second step is to calculate the joint surplus in each economic environment for each pattern of the workplace safety, $(S_h(\overline{k}), S_l(\overline{k}))$, $(S_h(\overline{k}), S_l(\underline{k}))$, $(S_h(\underline{k}), S_l(\overline{k}))$, and $(S_h(\underline{k}), S_l(\underline{k}))$, where $S_i(k)$ represents the joint surplus, $i = h, l$. The choice of the input for the workplace safety when the economy is in a recession or an economic boom is determined from this 2×2 one-stage simultaneous game.

We assume that $\overline{k} = 0.2$ and $\underline{k} = 0.1$, and furthermore, the rate of injury is defined by $\lambda(k) = 0.001/k$. Various parameter values are presented in Table 1. Table 2 displays numerical results. The first row considers the case where $k = 0.2$ is chosen during an economic boom while $k = 0.1$ is chosen during a recession. The second row shows the case where $k = 0.2$ is chosen, irrespective of the business cycle, followed by $k = 0.1$ irrespective of the business cycle in the third row and $k = 0.1$ during an economic boom and $k = 0.2$ during a recession in the final row. We now choose one of the four patterns. According to the 2×2 one-stage simultaneous game, when the economy is in an economic boom ($p = p_h$), $k = 0.2$ is the dominant strategy. It implies that a matching pair of a firm and a worker choose $k = 0.2$ during the economic boom, regardless of which one is chosen, $k = 0.1$ or $k = 0.2$ when the economy becomes downturn. In contrast, when the economy is in a recession ($p = p_l$), $k = 0.1$ is the dominant strategy. $k = 0.1$ is chosen during the recession, irrespective of which one is chosen when the economy becomes upturn. Therefore, the first row is a solution; that is, $k = 0.2$ is chosen during an economic boom while $k = 0.1$ is chosen during a recession.

Looking at the first row of Table 1, as the economy takes a cyclical upturn from p_l

to p_h, unemployment rate decreases from 0.0878 to 0.0234, and the amount of the input for workplace safety increases, thereby leading to lower rate of injury from 0.01 to 0.005. This result implies that not only the unemployment is countercyclical, but that the rate of injury is countercyclical; that is, we obtain the same implication as the steady state equilibrium obtained in Section 3.1 of a *positive* relationship between the unemployment rate and the rate of injury in the workplace.

3.3 Discussion

We have so far shown a positive relationship between the unemployment rate and the rate of injury in the workplace, incorporating the determinants of the input for workplace safety into an otherwise standard matching model. This mechanism may help explain why both the unemployment rate and the injury rate move countercyclically, as observed in the time-series data for some countries in Figure 1. However, as pointed out by Arai and Thoursie (2005), Ruhm (2000), and Boone and van Ours (2006), it is recognized that while the unemployment rate is countercyclical, the injury rate in the workplace is procyclical in some other countries according to Figure 1. How do we revise this model to capture the procyclical movement of the injury rate in the workplace?

Arai and Thoursie (2005) argue that firms hired even inexperienced workers who were more likely to be injured in the workplace during an economic boom, thus leading to the procyclical movement of the injury rate. One extension is to incorporate heterogeneous workers into the model. For example, there are two types of workers: veterans and beginners. We assume that veterans are less likely than beginners to be injured in the workplace. Firms initially attempt to match with veteran workers because the expected costs of loss incurred by workplace injury are low. As overall productivity rises during an economic boom, more firms enter the market, and then firms start to hire beginners as well as veterans because it is more difficult to meet and match with workers. The increase in employed beginners then drives up the injury rate in the workplace, in which case the injury rate is procyclical.

An alternative extension is much easier; that is, the injury rate is revised to the increase in productivity such that $\lambda(p,k)$ and $\partial\lambda/\partial p > 0$. The intuition to support this revision is as follows. During an economic boom, workers spend long hours at work under the condition of high labor adjustment costs, which increases the risk of attention problems in the workplace for workers and thereby the likelihood of injury. An increase in p induces firms to increase k and then lower the injury rate as shown in Section 3.1, but additionally, an increase in p directly raises the injury rate in the workplace. If the latter effect dominates the former, the injury rate becomes procyclical, and otherwise countercyclical.

4 Miscellaneous Issues

4.1 Unemployment and Sickness Benefits

This section returns to the steady states model introduced in Section 3.1 and incorporates sickness and unemployment benefits into the model to present their policy effects. These impacts then help illuminate the firms' incentives for the determinants of job creation and the amount of input for workplace safety in response to the policy changes. Here the emphasis lies on the impact of unemployment and sickness benefits on workplace safety. It appears that the linkage between these benefits and workplace safety has hitherto received little attention. The comparative statics exercise contributes to a better understanding of this linkage.

An employed worker who is actively engaged in work instantaneously earns w as before, but an employed worker who is absent from work because of work-related injury is recompensed for his or her loss through sickness benefits b. Additionally, an unemployed worker now receives unemployment benefits z. A nonlabor force participant who cannot look for a job because of the treatment of a work-related injury also receives the same amount of sickness benefits b. The value functions for a worker are modified by:

$$rW = w + \lambda(k)(W_a - W) + \delta(U - W),$$

$$rW_a = b + \alpha(W - W_a) + \delta(U - W_a),$$

$$rU = z + \theta q(\theta)(W - U),$$

and

$$rN = b + \alpha(U - N). \tag{26}$$

Because workers are risk neutral, sickness and unemployment benefits are merely considered subsidies. The value functions for a firm remain the same: eqs.(6), (7), and (8). We assume for simplicity that firms do not take out disability insurance; that is, firms do not pay the insurance premium and therefore do not receive disability insurance benefits faced by absent workers who are injured in the workplace.

Using these value functions and the free-entry condition, the wage is solved according to the Nash bargaining rule:

$$w = \beta \left[p - k + \frac{r + \alpha + \lambda(k)}{r + \alpha} \phi\theta \right] + (1 - \beta) \left[\frac{r + \alpha + \lambda(k)(z - b)}{r + \alpha} \right]. \tag{27}$$

Note that this wage equation is reduced to eq.(12) in the case of $b = z = 0$. It is appropriate to assume that sickness benefits are more generous than unemployment benefits; that is, $z < b$, in the case where an increase in the input for workplace safety k exerts an unambiguous impact on the wage. An increase in k lowers $(p-k)$, leading to the lower wage. In addition, an increase in k lowers the likelihood that an employee is injured in the workplace and raises the expected value of being employed relative to the value of being unemployed. The state of employment is more attractive, thus resulting in decreases in the reservation wage and thereby the wage. Alternatively, if $b > z$, an increase in k lowers the value of employment because employees are less likely to be injured and lose the chance of receiving a generous b. This makes the state of employment less attractive for workers, which raises the reservation wage and thereby the wage. The wage depends negatively on sickness benefits b. As an absent worker is recompensed more generously, the employment state is more favorable than the unemployment state, thus leading to the lower reservation wage and thereby the wage. In contrast, the wage increases with unemployment benefits z, which can be explained in the opposite way.

Similarly to Section 3.1, the nature of the equilibrium is characterized by (i) the condition to determine k through the Nash bargaining rule, (ii) the free-entry condition, and (iii) the steady-state conditions. The condition to determine k and the free-entry condition are then given by:

$$-\frac{\beta\lambda'(k)\delta\phi\theta}{r+\alpha} = (1-\beta)\left[\lambda'(k)(p-k) + (r+\alpha+\delta+\lambda(k)) + \lambda'(k)\frac{\delta z - (r+\alpha+\delta)b}{r+\alpha}\right], \tag{28}$$

and

$$\frac{q(\theta)(r+\alpha+\delta)}{(r+\delta)(r+\alpha+\delta+\lambda(k))}\left\{(1-\beta)\left[p-k-\frac{r+\alpha+\lambda(k)(z-b)}{r+\alpha}\right] - \beta\frac{r+\alpha+\lambda(k)}{r+\alpha}\phi\theta\right\} = \phi. \tag{29}$$

Eq.(28) is either upward or downward sloping in $k-\theta$ space, depending on the initial values of the parameters. To satisfy the second-order condition that ensures the maximization of the weighted product of the net return from the job match, eq.(28) is represented as an upward sloping curve in $k-\theta$ space. Meanwhile, eq.(29) is depicted as a horizontal line, similarly to eq.(14). The comparative statics show the characterizations of the equilibrium in response to the changes in the policy parameters.

We next explore the effects of the policy parameters (sickness and unemployment benefits) on the input for workplace safety and labor market tightness. According to the comparative statics analysis, we obtain the following results:

Proposition 3 *The comparative statics analysis provides the following characterizations:*

(a) sickness benefit:

$$\frac{dk}{db} \lesseqgtr 0 \quad \text{and} \quad \frac{d\theta}{db} > 0,$$

and (b) unemployment benefit:

$$\frac{dk}{dz} \gtrless 0 \quad and \quad \frac{d\theta}{dz} < 0.$$

The appendix provides further analytical detail.

(a) Sickness Benefit

Figure 5 illustrates the case in which eq.(28) is upward sloping as before. An increase in sickness benefits b shifts eq.(29) up and eq.(28) to the left, thus leading to a decrease in θ but an ambiguous change in k. An increase in sickness benefits b encourages firms to enter the market because the wage is lower according to eq.(27), thereby leading to a higher θ.

An increase in labor market tightness changes the firm's behavior toward the determinant of the input for workplace safety. There are two effects on k to be considered. First, according to eq.(28), an increase in θ lowers the marginal gain of operating an actively occupied job and the marginal cost with respect to k, the latter effect overwhelms the former, and therefore firms have an incentive to increase the amount of input for workplace safety. The second effect is described as follows. As b increases more, the difference between the value for an active employed W and the value for an absent employed W_a is smaller, which implies that workers faced with a larger b are more likely to accept the risk of injury. Therefore, firms are discouraged from buying k to keep their workplaces safe.

The overall effect of sickness benefits on workplace safety is then ambiguous. However, it is possible that sickness benefits exert a positive effect on the amount of workplace safety purchased by firms. One possible policy implication from this exercise is to increase sickness benefits, thereby inducing firms to pay more attention to workplace safety.

(b) Unemployment Benefit

The linkage between unemployment benefits and workplace safety is explored here. The intuitive explanations are completely opposite to those for the effect of sickness benefits discussed above. As unemployment benefits z increase, eq.(29) is shifted downward while eq.(28) is shifted to the right. This comparative statics exercise shows a decrease in θ but an ambiguous change in k. As in standard matching models, an increase in unemployment benefits z lowers labor market tightness θ. The intuition behind this result is that an increase in z raises the reservation wage of workers and thereby the wage, which encourages firms to exit.

There are two different effects on k. First of all, according to eq.(28), a decrease in θ raises the marginal gain of operating an actively occupied job and the marginal cost with respect to k. The latter effect dominates the former, so firms are encouraged to decrease the amount of the input for workplace safety. Secondly, an increase in z raises the value of unemployment, making the state of unemployment more favorable. To raise the expected value of employment for both an active worker and an absent worker, firms are induced to increase the amount of input for workplace safety to reduce the likelihood that the active employed is injured in the workplace and loses the wage.

The overall impact of unemployment benefits on the input for workplace safety is unambiguous. The graphical exercises are illustrated in Figure 6. This is with the emphasis on the novel result that unemployment benefits can have a positive, although indirect, effect on the input for workplace safety, implying a decrease in the risk of being injured in the workplace. Unemployment benefits may then encourage firms to improve working conditions.

4.2 Social Efficiency

This section shows the socially optimal solution and compares this with the solution of the decentralized economy presented above. The social planner optimally chooses labor market tightness θ and the amount of input for workplace safety k to maximize the discounted present value of net output. The social planner cannot affect the matching process and therefore shares the same matching constraints with workers and firms. The social planner's problem is illustrated below:

$$\max \int_0^\infty [(1-u-a-n)(p-k) - u\theta\phi]e^{-rt}dt,$$

subject to the flow conditions (15). In Appendix, we solve for the social planner's problem using the dynamic programming method. The socially optimal values of k and θ are solved by the following two equations:

$$-\frac{\lambda'(k)(r+\delta)\phi}{q(\theta)(r+\alpha+\delta)} = 1 + \eta(\theta)\left[\frac{-(r+\alpha)+\lambda'(k)\phi\theta}{r+\alpha}\right],$$

and

$$\frac{q(\theta)(r+\alpha+\delta)}{(r+\delta)(r+\alpha+\delta+\lambda(k))}\left[(1-\eta(\theta))(p-k)+\eta(\theta)\frac{r+\alpha+\lambda(k)}{r+\alpha}\phi\theta\right] = \phi,$$

where $\eta(\theta) \equiv -q'(\theta)\theta/q(\theta)$. The first equation represents the condition to determine k while the second shows the free-entry condition. These two equations correspond to eqs.(13) and (14) in the decentralized economy. Using eq.(14), eq.(13) can be rewritten as:

$$-\frac{\lambda'(k)(r+\delta)\phi}{q(\theta)(r+\alpha+\delta)} = 1 + \beta\left[\frac{-(r+\alpha)+\lambda'(k)\phi\theta}{r+\alpha}\right],$$

For early reference, eq.(14) is:

$$\frac{q(\theta)(r+\alpha+\delta)}{(r+\delta)(r+\alpha+\delta+\lambda(k))}\left[(1-\beta)(p-k)+\beta\frac{r+\alpha+\lambda(k)}{r+\alpha}\phi\theta\right] = \phi.$$

Comparing the socially optimal conditions with the conditions for the decentralized economy, we obtain the familiar result that the social optimal allocation for θ and k can be achieved in the decentralized economy if the Hosios condition is satisfied; that is, $\beta = -q'(\theta)\theta/q(\theta) \equiv \eta(\theta)$. According to the comparative statics analysis, we find $dk/d\beta \lesseqgtr 0$ and $d\theta/d\beta < 0$ (shown in the Appendix and Figure 7). An increase in β reduces the share of the surplus obtained by firms, thus discouraging them from entering the market. Therefore, θ is lower. Because eq.(13) is represented as an upward sloping curve in $k-\theta$ space, a lower θ leads to a decrease in k. Meanwhile, an increase in β lowers not only the marginal gain of operating an actively occupied job but also the marginal cost with respect to k, and the effect on the marginal cost is dominant because both k and w are simultaneously bargained. This implies that firms are induced to purchase more of the input for workplace safety k, shifting eq.(13) to the right. The overall effect on k is thus ambiguous.

Suppose that the socially optimal solutions are represented by $\widehat{k}$ and $\widehat{\theta}$ while the solutions derived in the decentralized economy are represented by k^* and θ^*. If $\beta > \eta(\widehat{\theta})$, we find that firms are underentered ($\widehat{\theta} > \theta^*$), but it is not clear whether the amount of workplace safety is over- or underpurchased in the decentralized economy ($\widehat{k} \lesseqgtr k^*$).

4.3 Timing and Decision Methods

This section discusses the different timings and decision methods other than that thus far presented. Two alternatives are to be considered. The first alternative is that a firm recruits a worker and chooses the amount of input for workplace safety, and then bargains the wage with the worker. The second is that firms simultaneously bargain about the wage and choose the amount of input for workplace safety after the worker is hired.

In the first case, k is a predetermined variable but w is not. The wage is continuously and instantaneously bargained in response to any change of k. The wage is thus considered a priori function of k, $w(k)$. We solve backwards for this problem. A firm bargains the wage $w(k)$ with an employee, and then chooses the optimal value of k to maximize the value of the job being actively occupied J, evaluated at $w(k)$. It is well-recognized in this case that we obtain the same result as that derived in Section 3, in which a firm simultaneously bargains w and k with an employee after recruitment.

The second case is different from the first in terms of the timing of the choice of k. Because a firm simultaneously bargains the wage and chooses the amount of input for workplace safety, the wage is no longer a priori function of k. We find that the firm chooses the lower amount of input for workplace safety in this timing of events than in the previous two frameworks. The firm decides how much to purchase k, facing a marginal cost of one, that is, a normalized price of k. On the other hand, in the previous two cases, firms have a marginal cost with a normalized price plus $w'(k)(< 0)$. In this case, firms simultaneously bargain w and choose k, not taking into account the marginal effect of $w(k)$. The analytical details are presented in the Appendix.

5 Concluding Remarks

This paper allows for decisions on the amount of input for workplace safety, and the trade-off between its cost and the risk of employed workers being absent from work because of work-related injuries.

By incorporating decisions on the amount of input for workplace safety in a search and matching model, we investigated the relationship between unemployment and the incidence of work-related injury. Productivity improvement encourages firm entry and raises labor market tightness. Greater competitiveness in finding an unemployed worker induces firms to increase the amount of input for workplace safety. Additionally, the productivity improvement raises profits, so the firms are induced to increase the input for workplace safety to prevent the potential loss of profit. Overall, the effect of the productivity improvement is positive on the amount of input for workplace safety and, in other words, negative on the risk of work-related injury. As for the impact on the unemployment rate, firm entry increases tightness in the labor market and thereby lowers the unemployment rate. The lower risk of injury in the workplace increase active employment but reduces absenteeism. The flow rate to unemployment is thus larger from active employment but smaller from absenteeism. The comparative statics analysis documents that the latter effect dominates the former, and therefore that an increase in the input for workplace safety lowers the unemployment rate. The overall effect of the productivity improvement is then negative on the unemployment rate through the input for workplace safety and labor market tightness.

This exercise shows that both the risk of injury and the unemployment rate are countercyclical. This implication may not be supported according to some data findings.

However, we clearly observe this relationship from other data sources. For example, the risk of injury along with the unemployment rate is countercyclical during at least some recent subperiods in Italy, the UK and Japan.

References

[1] Arai, M. and P. Skogman Thoursie (2005) "Incentive or Selection in Cyclical Absenteeism," *Labour Economics*, 12: pp. 269–80.

[2] Barmby, T., J. Sessions, and J. Treble (1994) "Absenteeism, Efficiency Wages and Shirking," *Scandinavian Journal of Economics*, 96: pp. 561–66.

[3] Bartel, A. P. and L. G. Thomas (1985) "Direct and Indirect Effects of Regulation: A New Look at OSHA7s Impact," *Journal of Law and Economics*, 28(1): pp. 1–25.

[4] Boone, J., and J. C. van Ours, (2006) "Are Recessions Good for Workplace Safety?" *Journal of Health Economics*, 25: pp. 1069–93.

[5] Ehrenberg, R. G. (1988) "Workers' Compensation, Wages, and the Risk of Injury," in John F. Burton, Jr., ed., *New Perspectives in Workers' Compensation*. Ithaca, NY: ILPR Press: pp. 71–96.

[6] Engström, P. and B. Holmlund (2007) "Worker Absenteeism in Search Equilibrium," *Scandinavian Journal of Economics*, 109(3): pp. 439–67.

[7] Garibaldi, P. and E. Wasmer (2005) "Labor Market Flows and Equilibrium Search Unemployment," *Journal of the European Economic Association*, 3(4): pp.851-82.

[8] Gray, W. B. and J. M. Mendeloff (2005) "The Declining Effects of OSHA Inspections on Manufacturing Injuries," 1979–1998, *Industrial and Labor Relations Review*, 58(4): pp. 571–87.

[9] Joll, C. (2008) "Employment Law," in K. Arrow and M. Inrilligator, ed., *Handbook of Law and Economics*, Vol. 2, Ch. 17: North-Holland, Amsterdam.

[10] Krueger, A. B. (1990) "Incentive Effects of Workers' Compensation Insurance," *Journal of Public Economics*, 41(1): pp. 33–50.

[11] Meyer, B. D., W. Kip Viscusi, and D. L. Durbin (1995) "Workers' Compensation and Injury Duration: Evidence from a Natural Experiment," *American Economic Review*, 85(3): pp. 322–40.

[12] Mortensen, D. T. and C. A. Pissarides (1994) "Job Creation and Job Destruction in the Theory of Unemployment," *Review of Economic Studies*, 61: pp. 397–415.

[13] Ruhm, C. J., (2000) "Are Recessions Good for your Health?," *Quarterly Journal of Economics*, 115: pp. 617–50.

[14] Scholz, J. T. and W. B. Gray (1990) "OSHA Enforcement and Workplace Injuries: A Behavioral Approach to Risk Assessment," *Journal of Risk and Uncertainty*, 3(3): pp. 283–305.

[15] Smith, R. S. "Have OSHA and workers' compensation made the workplace safer?," in D. Lewin, O. S. Mitchell, and P. D. Sherer, ed., *Research Frontiers in Industrial Relations and Human Resources*, Industrial Relations Research Association, Madison, *:* pp. 557–86.

[16] Ussif, A-A. (2004) "An International Analysis of Workplace Injuries," *Monthly Labor Review*, March: pp. 41–51.

[17] Viscusi, W. K. (1979) "The Impact of Workplace Safety Regulation," *Bell Journal of Economics*, 10(1): pp. 117–40.

[18] Viscusi, W. K. (1986) "The Impact of Workplace Safety Regulation," 1973–1983 *RAND Journal of Economics*, 17(4): pp. 567–80.

Appendix

Comparative Statics Effect (Section 3.1)

In this appendix, we use comparative statics analysis to explore the effects of productivity p on the input for workplace safety k and labor market tightness θ, using eq.(13)

and eq.(14). The comparative statics system is given by:

$$\begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} dk \\ d\theta \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \end{bmatrix} \begin{bmatrix} dp \\ d\alpha \\ d\beta \end{bmatrix},$$

where:

$$A_{11} = \lambda''(k) \left[\frac{\beta\phi\theta\delta}{r+\alpha} + (1-\beta)(p-k) \right] > 0,$$

$$A_{12} = \frac{\beta\lambda'(k)\phi\delta}{r+\alpha} < 0,$$

$$A_{21} = 0 \text{ from the first-order condition (eq.(13))},$$

$$A_{22} = \left(\frac{r+\alpha+\delta}{r+\delta} \right) \left[\frac{q'(\theta)(p-w-k)}{r+\alpha+\delta+\lambda(k)} - \frac{\beta q(\theta)(r+\alpha+\lambda(k))\phi}{(r+\alpha)(r+\alpha+\delta+\lambda(k))} \right] < 0,$$

$$B_{11} = -(1-\beta)\lambda'(k) > 0,$$

$$B_{12} = \frac{\beta\lambda'(k)\phi\theta\delta}{(r+\alpha)^2} - (1-\beta) < 0,$$

$$B_{13} = -\frac{\lambda'(k)\phi\theta}{r+\alpha} + [\lambda'(k)(p-k) + (r+\alpha+\delta+\lambda'(k)] > 0,$$

$$B_{21} = -\frac{q(\theta)(r+\alpha+\delta)(1-\beta)}{(r+\delta)(r+\alpha+\delta+\lambda(k))} < 0,$$

$$B_{22} = -\frac{q(\theta)\lambda(k)(p-w-k)}{(r+\delta)(r+\alpha+\delta+\lambda(k))^2} - \frac{(r+\alpha+\delta)q(\theta)}{(r+\delta)(r+\alpha+\delta+\lambda(k))}\left(\frac{\beta\lambda(k)\phi\theta}{(r+\alpha)^2}\right) < 0,$$

and

$$B_{23} = \frac{q(\theta)(r+\alpha+\delta)}{(r+\delta)(r+\alpha+\delta+\lambda(k))}\left[(p-k) + \frac{r+\alpha+\lambda(k)}{r+\alpha}\phi\theta\right] > 0,$$

where $w = \beta\left[p - k + \frac{r+\alpha+\lambda(k)}{r+\alpha}\phi\theta\right]$.

The Jacobian determinant is $\nabla_A \equiv A_{11}A_{22} - A_{12}A_{21} < 0$. Then we find:

$$\frac{dk}{dp} > 0, \text{ and } \frac{d\theta}{dp} > 0,$$

$$\frac{dk}{da} \gtrless 0, \text{ and } \frac{d\theta}{da} > 0,$$

and

$$\frac{dk}{d\beta} \gtrless 0, \text{ and } \frac{d\theta}{d\beta} < 0.$$

Comparative Statics Effect (Section 4.1)

The condition to determine k (eq. (28)) and the free-entry condition (eq. (29)) are rewritten here:

$$-\frac{\beta\lambda'(k)\delta\phi\theta}{r+\alpha} = (1-\beta)\left[\lambda'(k)(p-k) + (r+\alpha+\delta+\lambda(k)) + \lambda'(k)\frac{\delta z - (r+\alpha+\delta)b}{r+\alpha}\right],$$

$$\frac{q(\theta)(r+\alpha+\delta)}{(r+\delta)(r+\alpha+\delta+\lambda(k))}\left\{(1-\beta)\left[p - k - \frac{r+\alpha+\lambda(k)(z-b)}{r+\alpha}\right] - \beta\frac{r+\alpha+\lambda(k)}{r+\alpha}\phi\theta\right\} = \phi.$$

The comparative statics analysis is provided below to investigate the effects of the policy parameters:

$$\begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix} \begin{bmatrix} dk \\ d\theta \end{bmatrix} = \begin{bmatrix} D_{11} & D_{12} \\ D_{21} & D_{22} \end{bmatrix} \begin{bmatrix} db \\ dz \end{bmatrix},$$

where:

$$C_{11} = \frac{\beta\lambda''(k)\delta\phi\theta}{r+\alpha} + (1-\beta)\lambda''(k)\left[(p-k) + \frac{\delta z - (r+\alpha+\delta)b}{r+\alpha}\right] \lesseqgtr 0,$$

$$C_{12} = \frac{\beta\lambda'(k)\delta\phi}{r+\alpha} < 0,$$

$$C_{21} = 0 \text{ from the first-order condition (eq.(28))},$$

$$C_{22} = \frac{r+\alpha+\delta}{(r+\delta)(r+\alpha+\delta+\lambda(k))}\left[q'(\theta)(p-w-k) - \frac{\beta q(\theta)(r+\alpha+\lambda(k))\phi}{r+\alpha}\right] < 0,$$

$$D_{11} = \frac{(1-\beta)\lambda'(k)(r+\alpha+\delta)}{r+\alpha} < 0,$$

$$D_{12} = -\frac{(1-\beta)\lambda'(k)\delta}{r+\alpha} > 0,$$

$$D_{21} = -\frac{(1-\beta)q(\theta)(r+\alpha+\delta)\lambda(k)}{(r+\delta)(r+\alpha)(r+\alpha+\delta+\lambda(k))} < 0,$$

and

$$D_{22} = \frac{(1-\beta)q(\theta)(r+\alpha+\delta)(r+\alpha+\lambda(k))}{(r+\delta)(r+\alpha)(r+\alpha+\delta+\lambda(k))} > 0.$$

If $C_{11} > 0$, the second-order condition is satisfied such that the optimal amount of input maximizes the weighted product of the net return from the job match.

Social Efficiency (Section 4.2)

We attempt to solve for the social optimal allocation of (k, θ) using the dynamic programming method. The following value $V(u, a, n)$ is maximized with respect to k and θ:

$$
\begin{aligned}
rV(u,a,n) \;=\; & \max\{(1-u-a-n)(p-k) - u\theta\phi + V_1[\delta(1-u-a-n) + \alpha n - \theta q(\theta)u] \\
& + V_2[\lambda(k)(1-u-a-n) - (\alpha+\delta)a] + V_3[\delta a - \alpha n]\},
\end{aligned}
$$

where:

$$
V_1 = \frac{\partial V}{\partial u}, \quad V_2 = \frac{\partial V}{\partial a}, \quad V_3 = \frac{\partial V}{\partial n}.
$$

We surmise that the value takes a linear form in $u, a,$ and n and verify that our estimate is correct. Assuming $V = P_0 + P_1 u + P_2 a + P_3 n$, where $P_i s$ are parameters, it is then recognized that $V_1 = P_1$, $V_2 = P_2$ and $V_3 = P_3$. The first-order conditions are given:

$$
\phi = -P_1 q(\theta)[1-\eta(\theta)] \text{ where } \eta(\theta) = -q'(\theta)\theta/q(\theta), \tag{30}
$$

$$
P_2 \lambda'(k) = 1. \tag{31}
$$

The envelope conditions are obtained by:

$$
(p-k) + \theta\phi + P_1(r+\delta+\theta q(\theta)) + P_2\lambda(k) = 0, \tag{32}
$$

$$
(p-k) + P_1\delta + P_2(r+\alpha+\delta+\lambda(k)) - P_3\delta = 0, \tag{33}
$$

$$
(p-k) - P_1(\alpha-\delta) + P_2\lambda(k) + P_3(r+\alpha) = 0. \tag{34}
$$

Eqs. (32) - (34) solve for:

$$P_1 = -\frac{(r+\alpha)(r+\alpha+\delta)\left[(p-k)+\frac{r+\alpha+\lambda(k)}{r+\alpha}\phi\theta\right]}{(r+\alpha)(r+\delta+\theta q(\theta))(r+\alpha+\delta+\lambda(k))+\delta\lambda(k)\theta q(\theta)},$$

$$P_2 = \frac{-[(r+\alpha)(r+\delta)+\theta q(\theta)(r+\alpha+\delta)](p-k)+\delta(r+\delta)\phi\theta}{(r+\alpha)(r+\delta+\theta q(\theta))(r+\alpha+\delta+\lambda(k))+\delta\lambda(k)\theta q(\theta)}.$$

Substituting P_1 into eq. (30) yields:

$$\frac{q(\theta)(r+\alpha+\delta)}{(r+\delta)(r+\alpha+\delta+\lambda(k))}\left[(1-\eta(\theta))(p-k)+\eta(\theta)\frac{r+\alpha+\lambda(k)}{r+\alpha}\phi\theta\right]=\phi. \tag{35}$$

Recall the free-entry condition in the decentralized economy (eq. (14)):

$$\frac{q(\theta)(r+\alpha+\delta)}{(r+\delta)(r+\alpha+\delta+\lambda(k))}\left[(1-\beta)(p-k)+\beta\frac{r+\alpha+\lambda(k)}{r+\alpha}\phi\theta\right]=\phi.$$

If the Hosios condition ($\beta = \eta(\theta)$) is satisfied, the entry level coincides with the socially optimal level.

In a similar manner, substituting P_2 into eq. (31) gives:

$$\frac{-\lambda'(k)\{[(r+\alpha)(r+\delta)+\theta q(\theta)(r+\alpha+\delta)](p-k)+\delta(r+\delta)\phi\theta\}}{(r+\alpha)(r+\delta+\theta q(\theta))(r+\alpha+\delta+\lambda(k))+\delta\lambda(k)\theta q(\theta)}=1.$$

Using eq. (35), we obtain:

$$-\frac{\lambda'(k)(r+\delta)\phi}{q(\theta)(r+\alpha+\delta)}=1+\eta(\theta)\left[\frac{-(r+\alpha)+\lambda'(k)\phi\theta}{r+\alpha}\right]. \tag{36}$$

Correspondingly, eq. (13) is rewritten using eq. (14):

$$-\frac{\lambda'(k)(r+\delta)\phi}{q(\theta)(r+\alpha+\delta)}=1+\beta\left[\frac{-(r+\alpha)+\lambda'(k)\phi\theta}{r+\alpha}\right].$$

If the Hosios condition is satisfied, the amount of input for workplace safety coincides with the socially optimal amount.

Timing of Decisions and Methods (Section 4.3)

(a) A firm recruits a worker, chooses the amount of input for workplace safety k and then bargains the wage with the worker.

A firm chooses the optimal value of k to maximize the value of a job being actively occupied J (eq. (6)):

$$\max rJ = p - w(k) - k + \lambda(k)(J_a - J) + \delta(V - J),$$

where:

$$w(k) = \beta \left[p - k + \frac{r + \alpha + \lambda(k)}{r + \alpha} \phi\theta \right].$$

This wage takes the same form as that derived in Section 3 (eq. (12)). Because k is a predetermined variable, but w is not, the wage is bargained instantaneously in response to any change of k. Therefore, the wage is a priori function of k, $w(k)$. The firm chooses k, taking into account that the wage varies with k. The first-order condition is given by:

$$\lambda'(k)(J_a - J) = 1 + w'(k).$$

Using eq. (9) and (12), we obtain:

$$-\frac{\lambda'(k)}{r + \alpha + \delta + \lambda(k)} \left[(1 - \beta)(p - k) - \beta \frac{r + \alpha + \lambda(k)}{r + \alpha} \phi\theta \right] = 1 + \beta \left(-1 + \frac{\lambda'(k)}{r + \alpha} \phi\theta \right),$$

which coincides with eq. (13), the condition to determine k through the Nash bargaining solution.

(b) A firm recruits a worker, and then simultaneously chooses the amount of input for workplace safety k and bargains the wage with the worker.

Because the choice of k and the bargaining over w are made simultaneously, a firm chooses k, taking w as given. The firm's objective function is:

$$\max rJ = p - w - k + \lambda(k)(J_a - J) + \delta(V - J).$$

The first-order condition is:

$$\lambda'(k)(J_a - J) = 1.$$

Substituting eq. (9) and (12) rewrites the first-order condition as:

$$-\frac{\lambda'(k)}{r+\alpha+\delta+\lambda(k)}\left[(1-\beta)(p-k) - \beta\frac{r+\alpha+\lambda(k)}{r+\alpha}\phi\theta\right] = 1.$$

Comparing with eq. (13), the marginal cost with respect to k is overstated by $-\beta\left(-1+\frac{\lambda'(k)}{r+\alpha}\phi\theta\right)$ $(= w'(k))$. This implies that the firm purchases the lower amount of input for workplace safety in this framework.

Table 1: Paramters

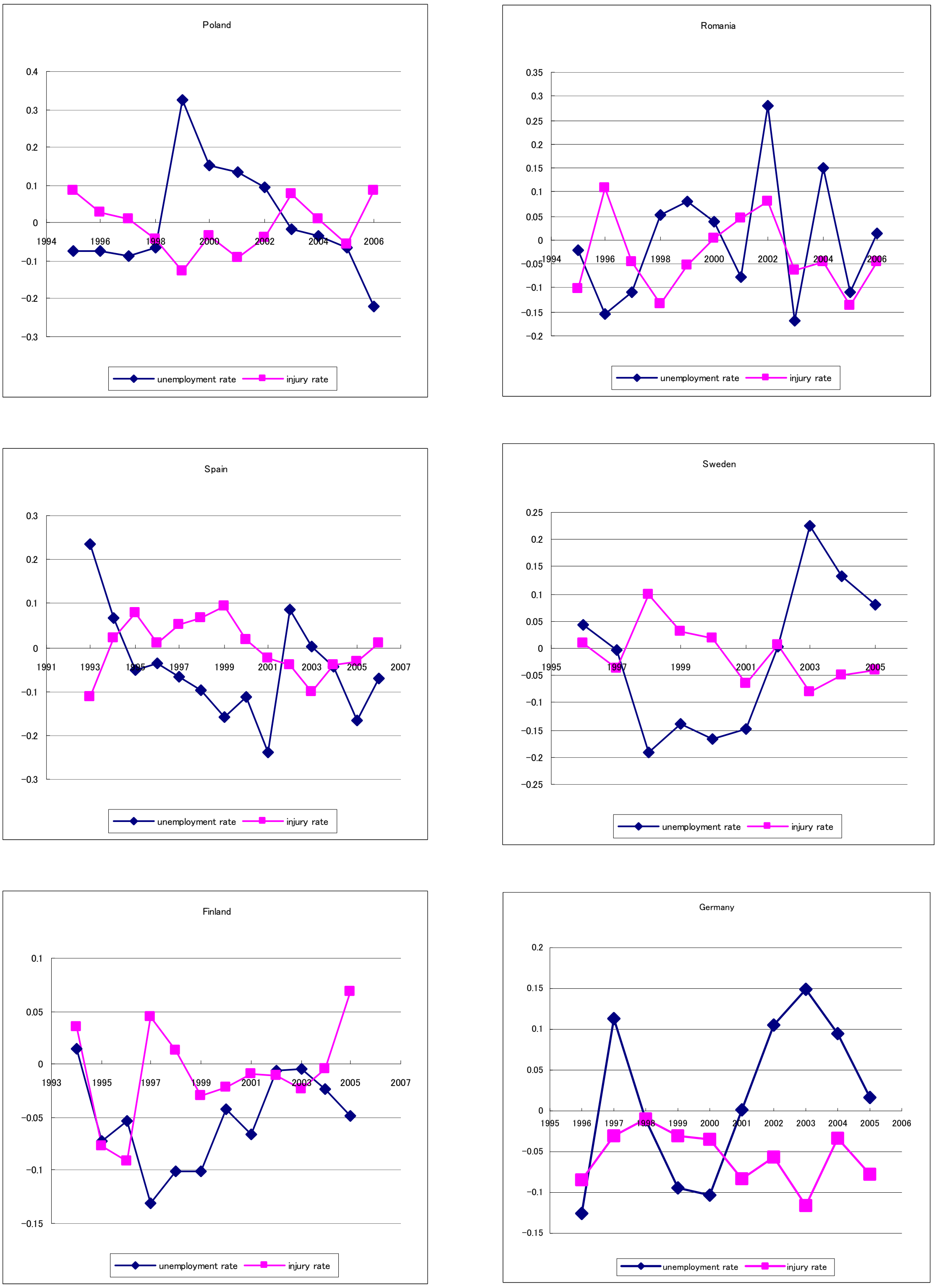
parameter	values
p_h	2
p_l	1
β	0.5
δ	0.001
r	0.02
ϕ	0.8
α	0.01
σ	0.005
$\overline{k}$	0.2
$\underline{k}$	0.1
$\lambda(\overline{k})$	0.005
$\lambda(\underline{k})$	0.01

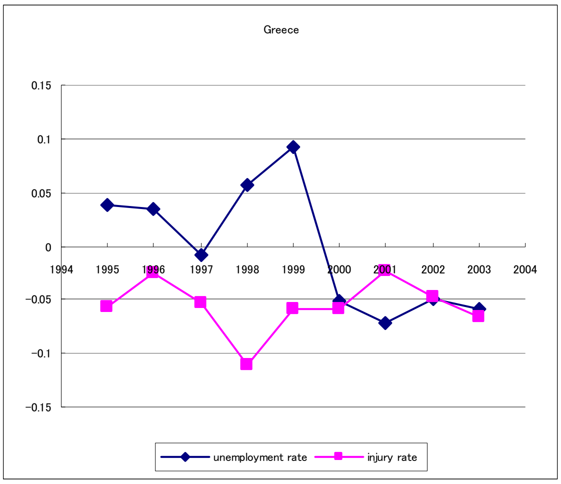
Table2: Numerical results

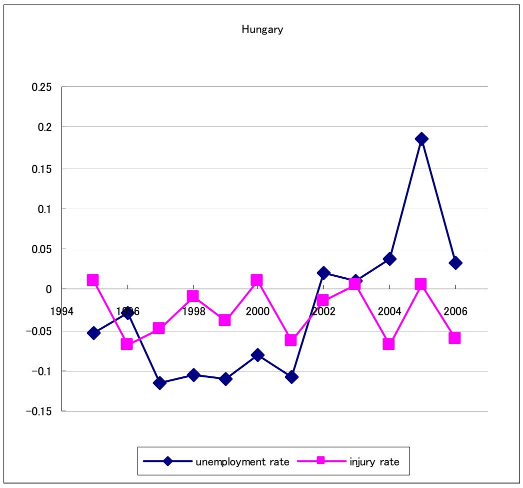
p	k	λ	θ	u	w	$S(k)$
p_h	0.2	0.005	1.6858	0.0234	1.771	1.039
p_l	0.1	0.01	0.2435	0.0878	0.893	0.395
p_h	0.2	0.005	1.7012	0.0233	1.771	1.043
p_l	0.2	0.005	0.7949	0.0654	0.795	0.356
p_h	0.1	0.01	1.5789	0.0365	1.869	1.005
p_l	0.1	0.01	0.2771	0.0827	0.891	0.421
p_h	0.1	0.01	1.5925	0.0363	1.869	1.010
p_l	0.2	0.005	0.2345	0.0604	0.794	0.387

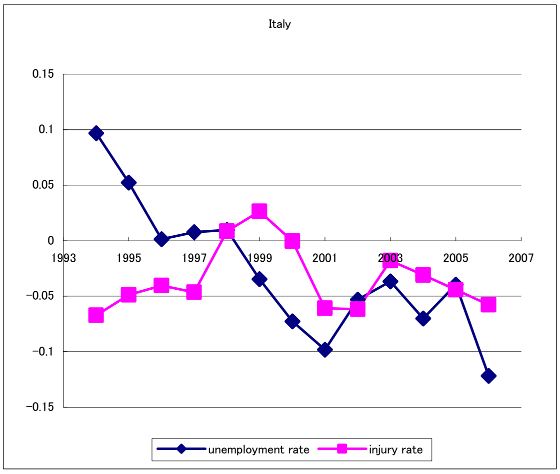
Note that we define $\lambda(k) = 0.001/k$ in this numerical exercise.

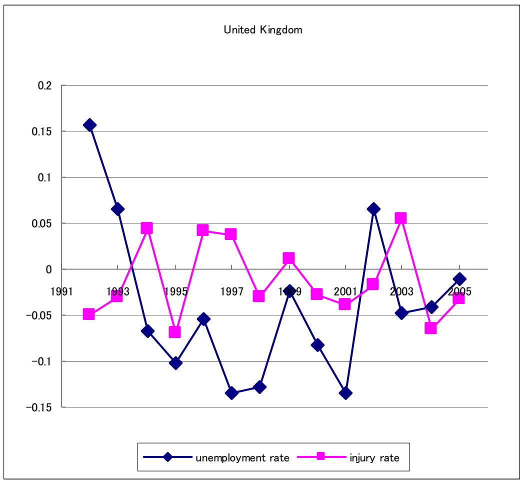
Figure 1: Injury Rate and Unemployment

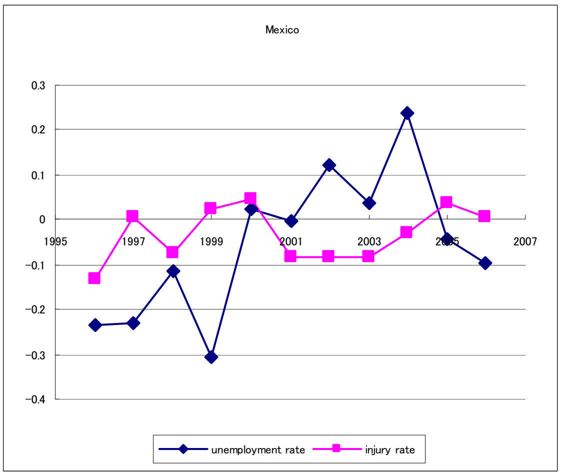


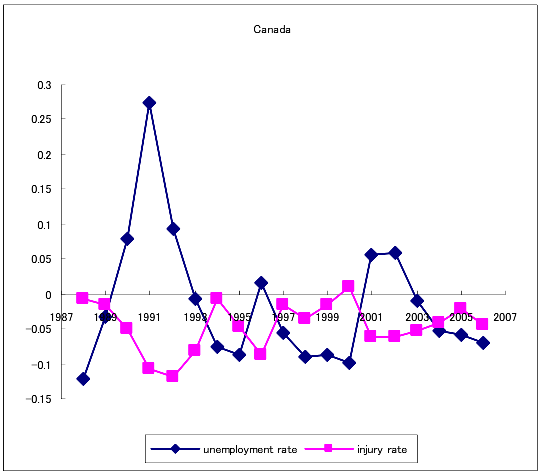

Greece
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
unemployment rate
injury rate

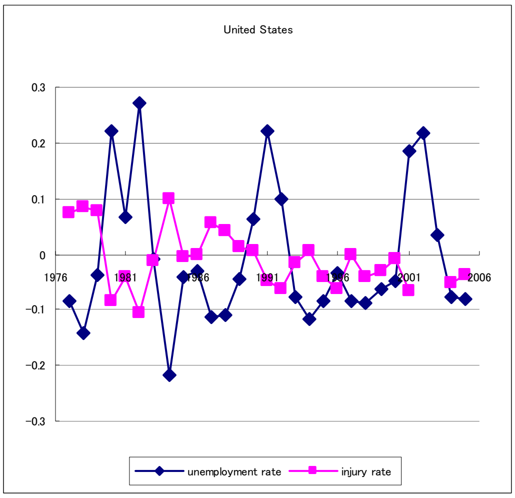

Hungary
0.25
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
1994 1996 1998 2000 2002 2004 2006
unemployment rate
injury rate


Italy
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
1993 1995 1997 1999 2001 2003 2005 2007
unemployment rate
injury rate


United Kingdom
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
1991 1993 1995 1997 1999 2001 2003 2005
unemployment rate
injury rate


Mexico
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
1995 1997 1999 2001 2003 2005 2007
unemployment rate
injury rate


Canada
0.3
0.25
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007
unemployment rate
injury rate


United States
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
1976
1981
1986
1991
1996
2001
2006
unemployment rate
injury rate

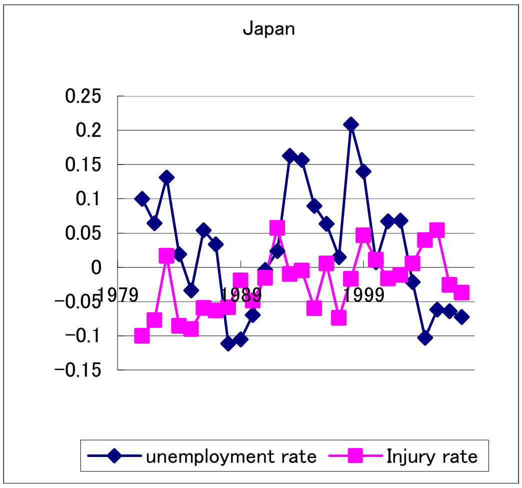

Japan
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
1979
1989
1999
unemployment rate
Injury rate

Figure 2: Equilibrium

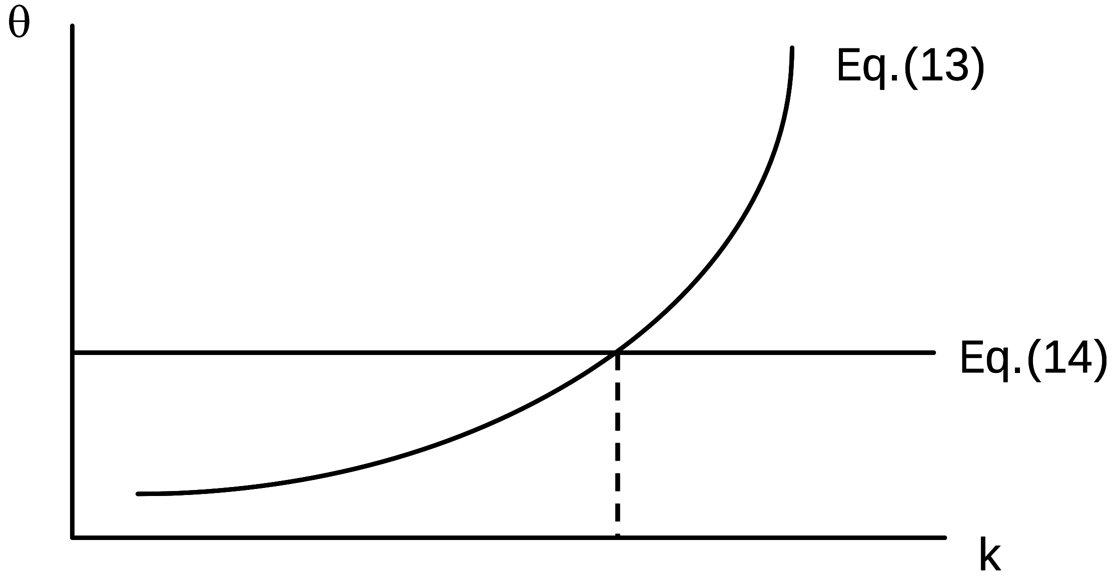


Figure 3: An Increase in Productivity

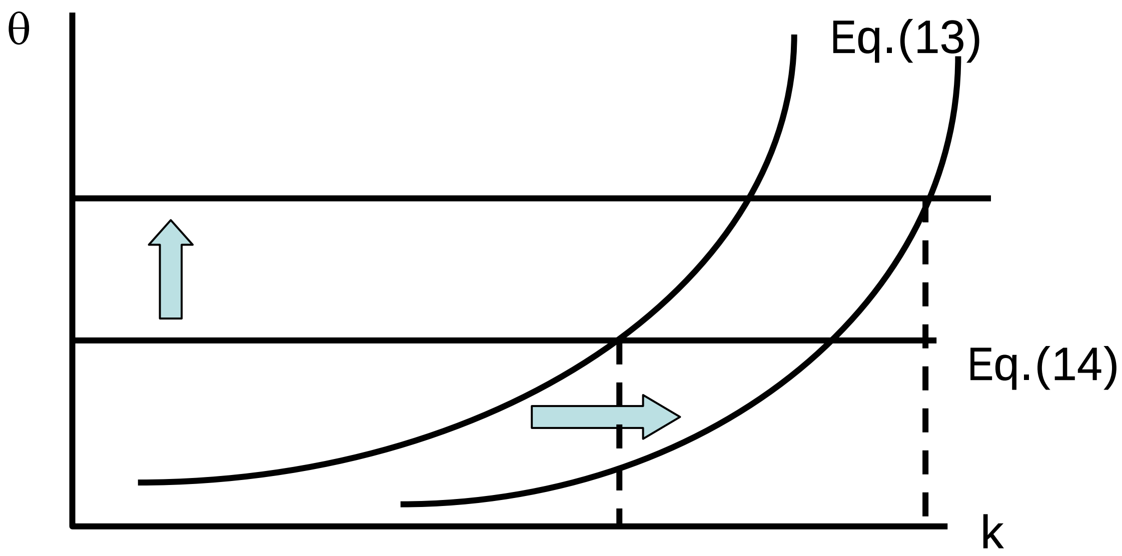


Figure 4: An Increase in Healing Rate

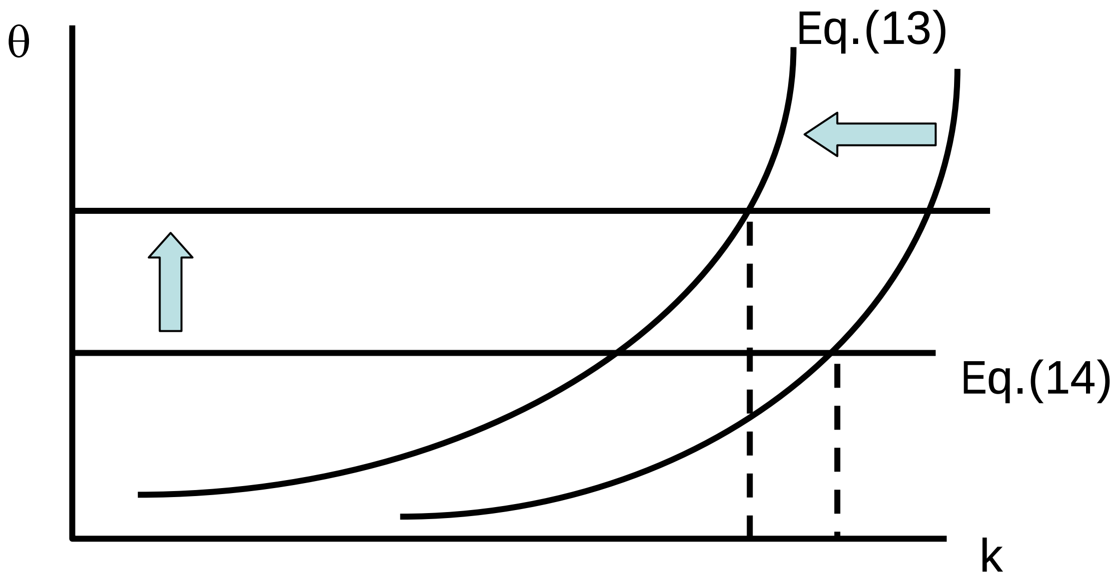


Figure 5: An Increase in Sickness Benefit

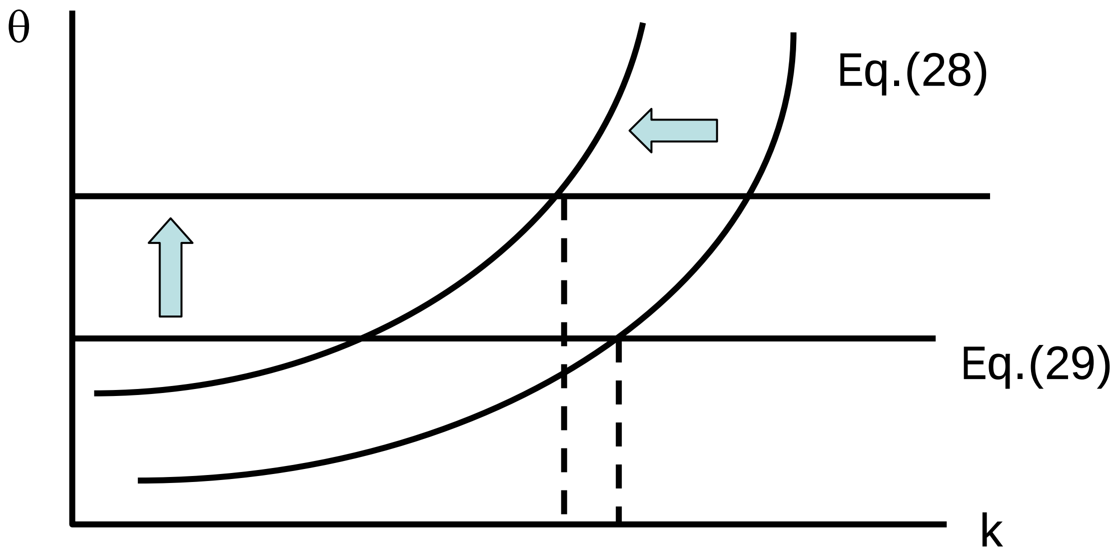


Figure 6: An Increase in Unemployment Benefit

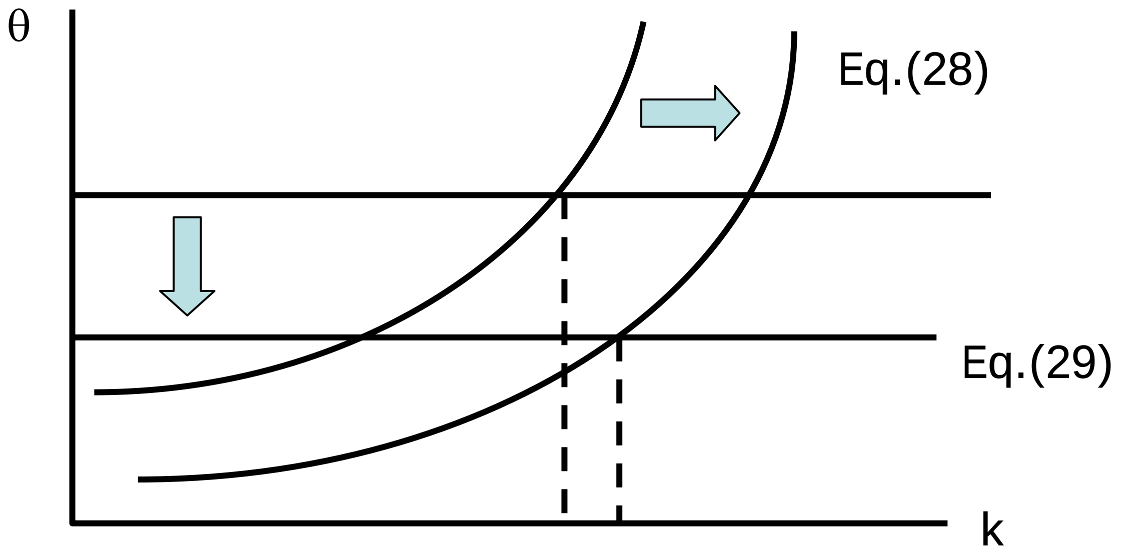


Figure 7: An Increase in β