

Unemployment and Workplace Safety in a Search and Matching Model*

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Abstract

This paper develops a model with search to examine the determinants of the amount of capital purchased by a firm for workplace safety and investigates a relationship between unemployment and the incidence of work-related injury or illness. Productivity improvement encourages firms' entry and therefore lowers the unemployment rate but instead raises the employment rate, including the fraction of absent workers (*scale effect*). On the other hand, productivity improvement encourages firms to buy more capital for workplace safety (*capital effect*). This biases the distribution of employed workers toward non-injured workers, lowering the fraction of absent workers. These two effects determine the relationship between unemployment and the incidence of work-related injuries or illnesses. The empirical exercises confirm that the scale effect had been dominant over the capital effect over the sample period in the US; that is, the unemployment rate and the flow rate of work-related injured workers moved in the opposite direction, but that a movement in the same direction is observed only from the late 1980s to the mid 1990s, so called the period of economic slowdown after the burst of "Bubble Economy" in Japan.

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1 Introduction

This paper develops a model with search to consider firms' determinants of the amount of capital for workplace safety and to explore a relationship between unemployment and the incidence of work-related injury or illness. Assuming that the probability of a worker being injured or taken ill at work sites depends negatively on the amount of capital for workplace safety purchased by firms, there is trade-off for the firms between the cost of its capital and the risk of losing a worker.

According to Robinson (1988) and Poteet and Didonato (2001), the number of work-related injuries is positively associated with employment size. They argued that during an economic boom in which labor demand exceeds labor supply, firms hire even inexperienced workers who are more likely to be injured at the work sites, and therefore that both employment size and flow of absent employed workers because of work-related injuries are large. In other word, the unemployment rate and the flow rate of absent employed workers are *negatively* correlated, controlling for the labor force.

However, Ussif (2004) undertook an international comparative study using time-series data between 1970 and 1999 from several countries and found an 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, controlling for the labor force. Additionally, he found movements of these two rates in the same direction if a time trend was controlled, which turns out to be consistent with the evidence from Robinson (1988) and Poteet and Didonato (2001). Ussif (2004) concluded that the number of work-related injuries had declined because of the technical advancement of workplace devices and environments captured by the time trend.

Using time-series data from the US and Japan, the first graphs of Figures 1 and 2 present movements of relative deviations of the unemployment rate and the fraction of work-related injured workers from their corresponding trends detrended by the Hodrick and Prescott filter. For the US, the relative deviations moved in the opposite direction over the sample period (1980-2001), implying a negative correlation between the unem-

ployment rate and a flow rate of work-related injured workers. Although not as clearly as the movement in the US, the same pattern can be seen in Japan except the late 1980s and the mid 1990s, following the burst of "Bubble Economy", but during which the relative deviations moved in the same direction. It means a positive correlation between the unemployment rate and the flow rate of work-related injured workers.

These results showed that during the stagnation period after the burst of the bubble economy in Japan, the number of work-related injuries was not determined only by the effect of employment size. We have not so far considered other elements determining the size of injuries at the work site, but to do so is of importance from policy makers' point of view as well as academic economists. There are many other factors affecting the rate of work-related injury, including employer practice at the work site, employee training, the role of unions, the technical advancement of work goods and environments as pointed out by Ussif (2004), the provision of mandates for safety, and investment in safety. This paper focuses attention on the last element among them, that is, investment in safety and develops a model that endogenizes the probability for a worker being subject to a work-related injury or illness in which a firm decides how much capital to purchase for workplace safety. Then we explore the optimal decision of firms that determines the number of injuries at the work site in response to exogenous shocks. Our contribution is to provide a new dimension to explain the relationship between the unemployment rate and the incidence of work-related injury or illness by incorporating the determinants of capital for workplace safety into a search-matching model. This paper does not discuss the role of mandates to keep workplaces safe by, for example, the Occupational Safety and Health Administration (OSHA) in the United States and its effect on labor market conditions.¹

There are a few theoretical studies in this field. Holmlund (2005) presented a model with individual search behavior and a decision on sickness absence with the framework of the stochastic utility function of sickness and analyzed the impact of social insurance on a worker's labor supply decision. He focused on an individual worker's decision on labor

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

supply and sickness absence. Our paper instead focuses on the determinant of the amount of capital purchased by *firms* for workplace safety to reduce the risk of losing employed workers because of work-related injuries or illnesses. One of the main findings in Holmlund (2005) is that an increase in sickness benefits raises the value of participating in the labor force, thereby resulting in an increase in employment size. Engström and Holmlund (2007) extended to a general equilibrium model with search by incorporating absence from work as an additional state.² They derived the optimal compensation package to maximize the expected profit affected by the number of job applications and sick workers' determinants of absence from work under the condition that accidents randomly arrived at workers. They provided the welfare analysis and compared with alternative social insurance policies.

Empirical studies in this area have thus far explored the effect of OSHA on work-related injuries using state-level, industry-level or plant-level data from the US.³ Overall, the effect of OSHA enforcement on the rate of work-related injuries was modest in the US (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 injuries using plant-level data of firms that were frequently inspected. According to the recent study by Mendeloff (2005), its significant relationship was observed in the early 1990s but it disappeared afterward.

Our findings are summarized below. Productivity improvement encourages firms to enter the labor market, which makes more competitive for firms to hire a worker. Firms that buy capital for workplace safety *before* meeting unemployed workers are then discouraged from doing so. On the other hand, productivity improvement leads to an increase in profit. In an environment in which firms have to recompense for a loss from a worker's absence, an increase in profit implies an increase in the opportunity cost that firms would have incurred if their workers had been injured or taken ill, which induces the firms to purchase more capital for workplace safety to reduce the risk of work-related injury or

²Barmby et al. (1994) presented a model in which the wage is endogenously determined within an efficiency wage setting. They showed that the wage is adjusted to affect the decision on sickness absence. Garibaldi and Wasmer (2001) also built a multistage model where the wage is endogenously determined.

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

illness. Which effect is more dominant is theoretically ambiguous. If the capital elasticity of the injury rate is sufficiently inelastic, the latter effect is more dominant over the former effect, in case of which productivity improvement raises the amount of capital for workplace safety and then lowers the fraction of absent employed workers. This is referred to as the *capital effect*. The amount of capital for workplace safety determines the distribution of employees between active and absent employed workers, but does not affect the unemployment rate.

There is another effect of productivity improvement through the labor market conditions. Productivity improvement encourages firms' entry as mentioned before, which raises labor market tightness and thereby lowers the unemployment rate. The larger employment size raises the number of workers who are absent from work because of work-related injuries or illnesses, holding the transition rate of being injured or taken ill fixed. This is referred to as the *scale effect*.

Overall, productivity improvement unambiguously lowers the unemployment rate but provides an ambiguous effect on the fraction of absent employed workers to the labor force. If the scale effect is dominant over the capital effect, the unemployment rate and the fraction of absent employed workers move in opposite directions in response to productivity improvement. However, in a case in which the capital effect is dominant, the same decreasing trends in the unemployment rate and the fraction of absent employed workers are observed as productivity improves.

The same argument can be applied to the flow of absent employed workers as well. In a case in which productivity improvement leads to an increase in the amount of capital for workplace safety, the transition rate from active employment to absence is lower, thus resulting in the lower flow rate of absent employed workers, holding the employment rate fixed (capital effect). On the other hand, the larger employment rate led to by firms' entry raises the flow rate of absent employed workers (scale effect) holding the transition rate of being injured or taken ill fixed. If the scale effect is dominant over the capital effect, the unemployment rate and the flow rate of absent employed workers are negatively correlated as argued by Robinson (1988) and Poteet and Didonato (2001). In

the reverse case, these two rates are positively correlated, which is consistent with Ussif (2004).

The amount of capital for workplace safety purchased by firms is a key variable that determines the relationship between unemployment and the incidence of work-related injury or illness. The puzzling empirical results could be partially explained by endogenizing the determinant of capital for workplace safety.

The model is extended to analyzing effects of various policy parameters (replacement rate, disability insurance payment and premium, and unemployment benefit). Among them, the effect of unemployment benefits is particularly noteworthy. To the best of our knowledge, unemployment benefit and workplace safety have been thus far discussed separately. We here show the strong linkage in policy between them. An increase in the unemployment benefit raises a worker's reservation wage and thereby the wage because the state of unemployment is more attractive for workers. It implies an increase in the cost that firms would have incurred if their workers had been injured or taken ill at the work site. Therefore, firms are encouraged to increase capital for workplace safety to reduce the likelihood of injury or illness at the work site. However, there is the opposite view; that is, the increasing wage lowers profit gained by firms, which discourages them from purchasing capital for workplace safety. Alternatively, a decrease in the profit encourages firms to exit, and less competitiveness then provides firms with incentives to raise capital for workplace safety because the probability of meeting a worker is higher. If the positive effects are dominant over the negative one, we recognize the novel result that an increase in unemployment benefit raises the amount of capital for workplace safety and thereby lowers the likelihood that employees are injured or taken ill at the work site.

We compare the effects on the flow rate of employees who become absent from work because of work-related injuries through changes in capital for workplace safety (capital effect) and labor market tightness (scale effect), using time-series data from the US and Japan.

The next section presents a matching model with an endogenous determinant of capital for workplace safety. Section 3 illustrates comparative statics exercises and discusses

a determinant of a relationship between unemployment and the incidence of work-related injury or illness by productivity improvement. The effects of various social insurance programs are analyzed in Section 4. Some evidences are presented in Section 5 to confirm implications obtained from the model. The final section provides concluding remarks.

2 The Model

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 preferences to work. At any moment, a worker is either unemployed, employed or absent from work because of work-related injury or illness. An employed worker is injured or taken ill at the work site and absent from work at a Poisson rate $\lambda(k)$, where k represents capital, with its price normalized to one, purchased by a firm to improve conditions of workplace safety. Work-related injuries and illnesses are defined here by immediate health hazard in the course of work that forces workers to be absent from work for treatment such as lower-back pain, cuts, bruises, broken bone, falls, struck by objects, mental illness and so on, but not by long-term latent health hazard from work such as pneumoconiosis. Following Acemoglu and Shimer (1999), a firm that creates job vacancies through free entry decides on how much capital k to buy for each job vacancy *before* meeting an unemployed worker.⁴ We deal with a situation in which devices for workplace safety are durable enough to exceed an employment duration of a first worker. An idea of *ex ante* investment in capital for workplace safety is then more favorable.⁵ A construction company installs handrails and safety net for falls at a construction site before hiring workers. A manufacturing company complies an instruction manual for workplace safety and health and purchases safety machines and devices when constructing a factory. These items are usually in long-lasting use. We assume that λ is characterized by $\lambda'(\cdot) < 0$,

⁴Acemoglu and Shimer (1999) determined how much capital to buy for production in a search model.

⁵In the reverse case, that is, if the devices for workplace safety are not durable enough, it is favorable to assume that capital for workplace safety is purchased *ex post*.

$\lambda''(\cdot) > 0$, $\lambda(0) = \bar{\lambda} \leq \infty$ and $\lim_{k \rightarrow \infty} \lambda(k) = \underline{\lambda} \geq 0$. As a firm buys capital to improve conditions of workplace safety, the probability of an employed worker being injured or taken ill is reduced at a decreasing rate.

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 the unemployed and v is the 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 labor market tightness, 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 destroyed at an exogenous Poisson rate δ , and then a worker becomes unemployed and begins to search for a job. Note here that a firm loses even a vacancy when the job is destroyed, which is different from the standard model with matching. Both workers and firms discount the future at the common rate r .

Various value functions are developed below. We begin with the value for an employed worker of engaging actively in work as follows:

$$rW(w) = w + \lambda(k)[W_a(w) - W(w)] + \delta[U - W(w)]. \quad (1)$$

The instantaneous utility is linear with earnings. The second term on the right-hand side of equation (1) represents the expected capital loss incurred by being injured or taken ill, and the third term indicates the expected capital loss of being unemployed. In a similar manner, the value for an employed worker of being absent from work because of work-related injury or illness is defined by:

$$rW_a(w) = w + \alpha[W(w) - W_a(w)] + \delta[U - W_a(w)]. \quad (2)$$

For convenience, a worker and firm have a contract that if being absent from work due to injury at the work site, the worker is compensated in full for her earning w . The absent

employed worker heals and returns to work at an exogenous Poisson rate α .⁶ Note that disutility incurred by the absent employed worker is ruled out in this model without loss of generality. Equations (1) and (2) thus show that the employed worker is indifferent between working and absence from work due to work-related injury or illness because the absent worker is fully compensated. Therefore, these values can be expressed in a standard form:

$$rW(w) = rW_a(w) = w + \delta[U - W(w)].$$

A worker's surplus is then calculated by:

$$W(w) - U = \frac{w - rU}{r + \delta}. \quad (3)$$

The value of unemployment is given as usual by:

$$rU = \theta q(\theta)[W(w) - U]. \quad (4)$$

At any moment, an unemployed worker, who is assumed to receive no instantaneous utility, meets a firm with a vacant job at the transition rate $\theta q(\theta)$.

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

The value of a job being occupied and active can be expressed as:

$$rJ(w, k) = p - w + \lambda(k)[J_a(w, k) - J(w, k)] - \delta J(w, k). \quad (5)$$

A matched pair produces p instantaneously. The second term on the right-hand side of

⁶In fact, the rate of return to work is not exogenous. It depends largely on the amount of compensations as well as the extent of injury or illness if it is difficult to observe whether or not absent workers heal from injury or get well from sickness. Meyer, Viscusi, and Durbin (1995) undertook a natural experiment and found that an increase in compensations received by absent employed workers extends the duration of absence. Similar results are obtained in Ehrenberg (1988) and Krueger (1990).

equation (5) represents the expected capital loss of a job being inactive because a worker is absent from work owing to work-related injury or illness. The third term indicates the expected capital loss of a job being destroyed.

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

$$rJ_a(w, k) = -w + \alpha[J(w, k) - J_a(w, k)] - \delta J_a(w, k). \quad (6)$$

We then assume that there are no disability insurance programs, and therefore that the firm has to compensate the absent worker for her/his wage according to the contract. It implies that renegotiation over the wage is not allowed between a worker and a firm after the injury or illness shock. We believe that this assumption is acceptable. In reality, many firms join the federal or state disability insurance programs with compulsory payroll deductions. If own employees are injured or taken ill at the work site, they are compensated through its program.⁷ Because the disability insurance program is mainly financed by firms, however, it is interpreted that firms indirectly bear the burden of compensation. Even though own employees become absent from work because of injury or illness that occurs out of the work site, many firms provide them with absence leave with payments. According to the survey conducted by Japanese Ministry of Health, Labour and Welfare (MHLW) in January 2008, 58.6% of surveyed Japanese firms have own absence leave programs, and 41.1% of them keep paying average 85.8-93.6% of salaries to absent employees. Putting down to surveyed firms over 1,000 employees, 85.3% have own absence leave programs, and 56.8% pays 88.5-91.8% of salaries to absent workers.⁸

The job turns out to be active at the rate α . Equations (5) and (6) give the following equation:

$$J(w, k) = \frac{(r + \alpha + \delta)p - (r + \alpha + \delta + \lambda(k))w}{(r + \delta)(r + \alpha + \delta + \lambda(k))}. \quad (7)$$

⁷We consider these effects on capital for workplace safety and labor market tightness later

⁸See *Rodo Sinbun* (Labour Newspaper) No. 2688 (July 14, 2008) in Japanese published by *Rodo Sinbunsha*.

The value of a vacancy is given by:

$$rV(k) = q(\theta)[J(w, k) - V(k)] - \delta V(k). \quad (8)$$

A vacancy is filled at the transition rate $q(\theta)$, but destroyed at the rate δ , similar to an occupied job.

The free entry condition ensures that the value of a vacancy equals k in equilibrium ($V(k) = k$). Using equation (8), the labor demand equation is thus given by:

$$k = \frac{q(\theta)J(w, k)}{r + \delta + q(\theta)}. \quad (9)$$

A firm and a worker consummate a match if and only if the joint surplus gained through this match is nonnegative, and then they share the joint surplus according to the Nash bargaining rule. Assuming that the worker's share of the surplus is defined by $\beta \in [0, 1]$, we have:

$$(1 - \beta)[W(w) - U] = \beta[J(w, k) - V(k)]. \quad (10)$$

Because renegotiation over the wage is not allowed after the injury or illness shock, the wage is determined, taking account of the possibility of a worker being injured in the future. Substituting equations (3) and (7) into equation (10) gives:

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

$\frac{r + \alpha + \delta}{r + \alpha + \delta + \lambda(k)} p$ is the expected productivity, and $(r + \delta)k$ is the cost of capital for workplace safety, accounting for the future discount rate r and the rate of destroying δ . According to the Nash bargaining rule, the wage is determined by the weighted-average of the expected profit (the first parentheses on the right-hand side) and the reservation wage rU . From equations (4), (9) and (10), the reservation wage rU can be expressed as $rU = \frac{\beta}{1 - \beta}(r + \delta)k\theta$. Substituting this into the above wage equation yields:

$$w = \beta \left[\frac{r + \alpha + \delta}{r + \alpha + \delta + \lambda(k)} p - (1 - \theta)(r + \delta)k \right]. \quad (11)$$

There are three effects of capital for workplace safety k on the wage. An increase in k raises the expected productivity $\frac{r+\alpha+\delta}{r+\alpha+\delta+\lambda(k)}p$ because of the lower likelihood that the employed worker is injured or taken ill at the work site and absent from work.⁹ $\theta(r+\delta)k$ is the total cost of capital for workplace safety per unemployed worker incurred by the firm. An increase in k provides the worker with extra bargaining power, directly reflecting the higher wage. These two effects therefore lead to an increase in the wage. On the other hand, an increase in k raises the cost of capital $(r + \delta)k$ and thereby lowers the expected profit, leading to a decrease in the wage. As seen in the wage equation (11), if $\theta \geq 1$; that is, the measure of vacancies is larger than the number of unemployed workers, the positive effects are unambiguously dominant over the negative effect.

Substituting this wage equation (11) into (7) gives the value for an occupied job of being active:

$$J(k, \theta) = \frac{(1 - \beta)(r + \alpha + \delta)p}{(r + \delta)(r + \alpha + \delta + \lambda(k))} + \frac{\beta(1 - \theta)(r + \delta)k}{r + \delta}.$$

The first term on the right-hand side shows that an increase in capital for workplace safety k raises the expected productivity and thereby the value for an occupied job of being active. The second term shows that an increase in k lowers the value of an occupied job if $\theta \geq 1$ because the higher wage is burdensome for firms. If $\theta < 1$, an increase in k strictly raises the value of an occupied job. The free entry condition can be rewritten by substituting this into equation (9):

$$\frac{q(\theta)}{r + \delta + q(\theta)} \left[\frac{(1 - \beta)(r + \alpha + \delta)p}{(r + \delta)(r + \alpha + \delta + \lambda(k))} + \frac{\beta(1 - \theta)(r + \delta)k}{r + \delta} \right] = k. \quad (12)$$

⁹Suppose that renegotiation is allowed after the injury or illness shock. The wage for an active worker is computed by $w = \beta [p - (1 - \theta)(r + \delta)k]$ while the wage for an absent worker because of injury or illness is $w = -\beta(1 - \theta)(r + \delta)k$. As we would expect, the wage is higher when the renegotiation is allowed than when it is not. The wage for an absent worker turns to be negative because firms have to recover the cost for *ex ante* investment in capital for workplace safety from the absent worker. Unless the expected capital gain of the absent worker by recovering from injury or illness to the work site is sufficiently large, it is better off for the absent worker to quit and become unemployed.

We move to the problem regarding the optimal choice of capital for workplace safety. A firm chooses the optimal capital for workplace safety per job vacancy to maximize the expected value of a vacancy:

$$\max_k V(k) - k \implies \max_k \frac{q(\theta)}{r + \delta + q(\theta)} J(k, \theta) - k.$$

The first-order condition yields:

$$\frac{q(\theta)}{r + \delta + q(\theta)} \left[-\frac{(1 - \beta)(r + \alpha + \delta)\lambda'(k)p}{(r + \delta)(r + \alpha + \delta + \lambda(k))^2} + \beta(1 - \theta) \right] = 1. \quad (13)$$

The left-hand side term represents the expected marginal value of an occupied job with respect to the capital for workplace safety while the right-hand side term is its marginal cost, that is, the price of capital normalized to one.

According to the second-order condition, the slope of the marginal value of an occupied job described above is computed as:

$$\begin{aligned} \frac{\partial^2 V(k)}{\partial k^2} &= \left[\frac{q(\theta)}{r + \delta + q(\theta)} \right] \frac{\partial^2 J(k, \theta)}{\partial k^2} = \left[\frac{q(\theta)}{r + \delta + q(\theta)} \right] \left[-\frac{(1 - \beta)(r + \alpha + \delta)p}{r + \delta} \right] \\ &\quad \times \frac{\lambda''(k)(r + \alpha + \delta + \lambda(k)) - 2(\lambda'(k))^2}{(r + \alpha + \delta + \lambda(k))^3}. \end{aligned}$$

If $\lambda''(k)(r + \alpha + \delta + \lambda(k)) - 2(\lambda'(k))^2 > 0$ for all k , then this is sufficient to show that the optimal capital level maximizes the value of a vacancy.¹⁰

Next, steady-state conditions are illustrated to derive the unemployment rate and the rate of absent employed workers. Let u and a denote fractions of unemployed workers and employed workers who are absent from work because of work-related injuries or illnesses, respectively. The steady-state conditions require first of all that the inflow rate to the unemployment pool equals the outflow rate from it, and secondly that the inflow rate to the absent pool equals the outflow rate from it,

¹⁰If $\lambda(k) = 1/(1 + k)$, for example, $\lambda''(k)(r + \alpha + \delta + \lambda(k)) - 2(\lambda'(k))^2 = 2(r + \alpha + \delta)/(1 + k)^3 > 0$

$$\theta q(\theta)u = \delta(1 - u - a) + \delta a = \delta(1 - u),$$

$$\text{and } (\alpha + \delta)a = \lambda(k)(1 - u - a).$$

Then we obtain:

$$\begin{aligned} u &= \frac{\delta}{\delta + \theta q(\theta)}, \\ \text{and } a &= \left(\frac{\lambda(k)}{\alpha + \delta + \lambda(k)} \right) \left(\frac{\theta q(\theta)}{\delta + \theta q(\theta)} \right). \end{aligned} \tag{14}$$

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

$$1 - u - a = \left(\frac{\alpha + \delta}{\alpha + \delta + \lambda(k)} \right) \left(\frac{\theta q(\theta)}{\delta + \theta q(\theta)} \right). \tag{15}$$

As one would expect, the higher labor market tightness θ lowers the unemployment rate, u but raises the fraction of absent employed workers a because the number of employed workers is larger. An increase in capital for workplace safety k lowers the fraction of absent employed a because workplace safety conditions are improved, but k does not affect u . A change of k just influences the distribution between active and absent employed workers.

The nature of equilibrium is characterized by the free entry condition, the first-order condition to determine the optimal level of capital, and the steady-state conditions. Equations (12), (13) and (14) provide a complete description of equilibrium to solve for the vector (k, θ, u, a) . For convenience, these equilibrium conditions are summarized below.

(i) First-order condition (equation (12))

$$\frac{q(\theta)}{r + \delta + q(\theta)} \left[-\frac{(1 - \beta)(r + \alpha + \delta)\lambda'(k)p}{(r + \delta)(r + \alpha + \delta + \lambda(k))^2} + \beta(1 - \theta) \right] = 1,$$

(ii) Free entry condition (equation (13))

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

and (iii) Steady-state conditions (equation (14))

$$u = \frac{\delta}{\delta + \theta q(\theta)},$$

$$\text{and } a = \left(\frac{\lambda(k)}{\alpha + \delta + \lambda(k)} \right) \left(\frac{\theta q(\theta)}{\delta + \theta q(\theta)} \right).$$

We investigate the characterizations of the equilibrium by examining the comparative statics in the next section.

3 The Relationship between Unemployment and the Incidence of Injury or Illness

Our concerns focus on a relationship between unemployment rate and the incidence of work-related injury or illness via exogenous parameter changes. We first pick up productivity p as a key parameter. This exercise helps provide an explanation about the puzzling results obtained from data findings.

Does productivity improvement encourage firms to raise the amount of capital for workplace safety as well as to enter the labor market? The main purpose in this subsection is to illustrate changes in workplace safety and labor market conditions in response to productivity improvement. Using (i) first-order conditions and (ii) free entry conditions, the comparative statics system is described. The appendix section shows the analytical details.

Proposition 1 *The comparative statics analysis provides the following characterizations:*

$$\frac{dk}{dp} \begin{matrix} \leq \\ > \end{matrix} 0, \text{ and } \frac{d\theta}{dp} \geq 0.$$

As one would expect, an increase in productivity p raises labor market tightness 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 . If $\beta = 1$; that is, there is no bargaining power over the wage determination for firms, firms do not have incentives to enter the labor market despite the fact that productivity improves, and therefore $d\theta/dp = 0$.

An increase in productivity p has two effects on the optimal capital for workplace safety k . On the one hand, because more vacancies created newly due to productivity improvement make it more difficult for firms to find unemployed workers, firms that buy capital for workplace safety k *before* matching are discouraged from doing so.¹¹ On the other hand, an increase in productivity implies an increase in profit that firms would have earned without workers' absence from work. It therefore encourages firms to increase their capital for workplace safety k to prevent employed workers from being injured or taken ill at the work sites. Which effect is dominant is theoretically ambiguous. According to the comparative statics analysis shown in Appendix, we find that the positive effect on capital is more likely to dominate as the injury rate $\lambda(k)$ is more inelastic; that is, as a marginal decrease in $\lambda(k)$ is larger, firms are encouraged to buy more capital for workplace safety k to reduce the likelihood that accidents occur. If $\beta = 1$, both opposite effects are canceled out, and therefore, productivity improvement does not affect the amount of capital for workplace safety ($dk/dp = 0$).

We next consider the effect on the unemployment rate and the fraction of workers who are absent from work because of work-related injuries or illnesses. Using (iii) steady-state conditions (equation (14)), the total derivatives of these equations are taken with respect to p :

$$\frac{du}{dp} = \underbrace{\left\{ -\frac{\delta}{[\delta + \theta q(\theta)]^2} \right\}}_{-} \underbrace{\left(\frac{\partial \theta q(\theta)}{\partial \theta} \right) \left(\frac{d\theta}{dp} \right)}_{+} \leq 0, \quad (16)$$

and

¹¹In a case that firms buy capital for workplace safety *after* hiring (*ex post* investment in safety), this negative effect of productivity on capital for workplace safety disappear.

$$\frac{da}{dp} = \underbrace{\left(\frac{(\alpha + \delta)\lambda'(k)}{[\alpha + \delta + \lambda(k)]^2} \right)}_{-} \underbrace{\left(\frac{\theta q(\theta)}{\delta + \theta q(\theta)} \right)}_{+/-} \left(\frac{dk}{dp} \right) + \underbrace{\left(\frac{\lambda(k)}{\alpha + \delta + \lambda(k)} \right)}_{+} \underbrace{\left(\frac{\delta}{[\delta + \theta q(\theta)]^2} \right)}_{+} \underbrace{\left(\frac{\partial \theta q(\theta)}{\partial \theta} \right)}_{+} \left(\frac{d\theta}{dp} \right). \quad (17)$$

The term on the right-hand side in equation (16) and the second term on the right-hand side in equation (17) show that higher labor market tightness caused by productivity improvement lowers the unemployment rate u but raises the fraction of absent employed workers a . The entry of more firms raises the likelihood for unemployed workers of obtaining a job and thereby the employment rate. An increase in the employment rate results directly in an increase in the fraction of absent employed workers because of work-related injuries or illnesses, holding the transition rate of work-related injury or illness fixed. This is referred to as the *scale effect*.

Looking at the first term on the right-hand side in equation (17), in a case that the productivity improvement raises the amount of capital for workplace safety k , the fraction of absent employed workers is lower. This is because an increase in k reduces the likelihood that employed workers are injured or taken ill at the work sites and absent from work $\lambda(k)$. In the opposite case, productivity improvement leads to the higher fraction of absent employed workers through a decrease in the amount of capital for workplace safety. This effect through capital for workplace safety is referred to as the *capital effect*. It causes a transfer between active employed workers $(1 - u - a)$ and absent employed workers a in the distribution of employees, holding the transition rates between employment and unemployment fixed. As seen in equation (16), there is no capital effect on u . Its effect affects only the distribution of employees between active workers and absent employed workers.

The implications are summarized below:

Proposition 2 *As productivity improves, (a) (scale effect) the unemployment rate is lower, but the fractions of absent and active employed workers are higher; (b) (capital effect 1)*

if firms are encouraged to purchase more (less) capital for workplace safety, the fraction of absent employed workers is lower (higher), but the fraction of active employed workers is higher (lower); and (c) (capital effect 2) there is no effect on the unemployment rate through a change of capital for workplace safety.

Although the scale effect of productivity improvement on u is unambiguously negative, the combined capital and scale effects on a cannot be determined with certainty if $dk/dp > 0$ from equation (17). If the capital effect is dominant over the scale effect, the overall effect of productivity is negative on a . Therefore, u and a are positively correlated through productivity improvement. On the other hand, if the scale effect is dominant over the capital effect, u and a are negatively correlated. What are the factors determining the magnitude relation between the capital and scale effects? One of them is the elasticity of $\lambda(k)$; that is, as $\lambda(k)$ is inelastic with respect to k , it is more likely that the capital effect dominates the the scale effect, thus resulting in the positive relationship between u and a . These implications are summarized.

Proposition 3 *Suppose $dk/dp > 0$. As productivity improves, (a) if the capital effect is dominant over the scale effect, the unemployment rate, u and the fraction of workers who are absent from work because of work-related injuries or illnesses, a move downward in the same direction; and (b) in the reverse case, the unemployment rate, u moves downward while the fraction of workers who are absent from work because of work-related injuries, a moves upward.*

We have so far paid attention on the stock of injured employed, but our concern shifts to an impact of production on the *flow* of injured employed and its relationship with unemployment rate. It has been argued by policy makers and OSH specialists that the flow of employed who become injured or ill at the work sites is positively associated with the employment size according to the scale effect. This view was supported by Robinson (1988) and Poteet and Didonato (2001). In other words, it implies that the flow rate of employed workers who become injured or ill and the unemployment rate are *negatively* correlated, holding the labor force fixed.

However, Ussif (2004) showed an opposite view that despite a steady increase in the number of employed workers, the number of work-related injuries had declined from 1970 to 1999 using time-series data from selected countries (Canada, Finland, France, US, and Sweden). That is, he implied a *positive* relationship between the unemployment rate and the flow rate of employed workers who become injured.

What are those arguments omitting to be unable to explain this relationship between the unemployment rate and the flow rate of absent employed found in the data? Our model incorporating the capital effect through a determinant of capital for workplace safety k in the search and matching framework helps provide some implications consistent with the data. Capital and scale effects on u and the flow rate of absent employed workers $\lambda(k)(1 - u - \alpha)$ alike illustrate a different relationship between them.

According to equation (15), the flow rate of absent employed workers because of work-related injuries or illnesses, y can be expressed as,

$$y = \lambda(k)(1 - u - a) = \lambda(k) \left(\frac{\alpha + \delta}{\alpha + \delta + \lambda(k)} \right) \left(\frac{\theta q(\theta)}{\delta + \theta q(\theta)} \right).$$

Then, the total derivative of this flow equation are taken with respect to p :

$$\begin{aligned} \frac{dy}{dp} = & \underbrace{\lambda'(k) \left(\frac{\alpha + \delta}{\alpha + \delta + \lambda(k)} \right)^2 \left(\frac{\theta q(\theta)}{\delta + \theta q(\theta)} \right)}_{-} \underbrace{\left(\frac{dk}{dp} \right)}_{+/-} \\ & + \underbrace{\lambda(k) \left(\frac{\alpha + \delta}{\alpha + \delta + \lambda(k)} \right) \left(\frac{\delta}{[\delta + \theta q(\theta)]^2} \right)}_{+} \underbrace{\left(\frac{\partial \theta q(\theta)}{\partial \theta} \right) \left(\frac{d\theta}{dp} \right)}_{+}. \end{aligned} \quad (18)$$

The first term on the right-hand side of equation (18) shows the capital effect; that is, in a case that firms buy more capital for workplace safety k in response to productivity improvement ($dk/dp > 0$), the probability of being injured or taken ill at the work site $\lambda(k)$ is lower, resulting in a decrease in the flow rate of absent employed workers because of work-related injuries or illnesses to the absent employed pool. The same argument can be applied in the reverse case. The second term reveals the scale effect; that is, as more

firms enter the market and create vacancies due to productivity improvement, the flow rate of absent employed workers increases because of the increasing number of employed workers.

Confining our argument to $dk/dp > 0$, if the scale effect is dominant over the capital effect, the productivity improvement leads to a decrease in the unemployment rate u but an increase in the flow rate of absent employed workers $\lambda(k)(1-u-a)$. These two rates are negatively correlated, as argued by Robinson (1988) and Poteet and Didonato (2001). If productivity is pro-cyclical, this implication is consistent with the empirical finding from Arai and Skogman Thoursie (2005) showing that the extent of sickness absence is strongly pro-cyclical. If the scale effect is instead dominant, throughout a change in capital for workplace safety k in response to a productivity shock u and $\lambda(k)(1-u-a)$ alike move downward in the same direction. This implication is consistent with the data finding from Ussif (2004). The sign of y depends entirely on which effect is more dominant, the capital effect or the capital effect. The next proposition summarizes:

Proposition 4 *Suppose $dk/dp > 0$. As productivity improves, (a) if the capital effect is dominant over the scale effect, the unemployment rate, u and the flow rate of workers who are absent from work because of work-related injuries or illnesses, $\lambda(k)(1-u-a)$ move downward in the same direction; and (b) in the reverse case, the unemployment rate, u moves downward while the flow rate of workers who are absent from work because of work-related injuries or illnesses, $\lambda(k)(1-u-a)$ moves upward.*

In Section 5, some evidences are provided.

4 Applications

This section presents the effects of various policy parameters: replacement rate, disability insurance payment, disability insurance premium, and unemployment benefits. These impacts illuminate firms' incentives for determinants of job creation and the amount of capital for workplace safety in response to policy changes. Here is with the emphasis on the impact of unemployment benefits on workplace safety. It appears that the linkage

between unemployment benefits and workplace safety has not at least thus far been argued. This comparative statics exercise contributes to illuminating its linkage.

4.1 The Extended Model

An employed worker who is actively engaged in work instantaneously earns w as heretofore, but an employed worker who is absent from work because of work-related injury or illness is recompensed not fully but partially for her/his loss by ρw where ρ represents the replacement rate ($\rho \in (0, 1)$). Additionally, an unemployed worker now receives the unemployment insurance benefits z . The value functions for a worker are modified by:

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

$$rW_a(w) = \rho w + \alpha[W(w) - W_a(w)] + \delta[U - W_a(w)],$$

and

$$rU = z + \theta q(\theta)[W(w) - U]. \quad (19)$$

We assume that the compensation for work-related injury or illness ρw exceeds the unemployment insurance benefits z , which is more realistic. Since workers are risk-neutral, unemployment benefits are considered just as a subsidy. In a similar manner, the value functions for a firm are:

$$rJ(w, k) = p - (1 + t)w + \lambda(k)[J_a(w, k) - J(w, k)] - \delta J(w, k),$$

$$rJ_a(w, k) = -\rho w + \phi w - tw + \alpha[J(w, k) - J_a(w, k)] - \delta J_a(w, k),$$

and

$$rV(k) = q(\theta)[J(w, k) - V(k)] - \delta V(k). \quad (20)$$

Firms that hire workers take out disability insurance and pay the insurance premium tw . A firm has to recompense an injured worker for her/his loss by part of the wage ρw but receives ϕw in disability insurance benefits. We assume $1 > \rho > \phi > t > 0$; that is, the disability insurance program does not fully cover a firm's loss, and the insurance premium is lower than the insurance payment.

Using equations (19) and (20) and the free entry condition ($V(k) = k$), the wage is solved according to the Nash bargaining rule:

$$w = \frac{\beta[(r + \alpha + \delta)p - (1 - \theta)(r + \delta)(r + \alpha + \delta + \lambda(k))k] + (1 - \beta)[r + \alpha + \delta + \lambda(k)]z}{\beta[(1 + t)(r + \alpha + \delta) + \lambda(k)(t + \rho - \phi)] + (1 - \beta)[r + \alpha + \delta + \rho\lambda(k)]}.$$

Be aware that this wage equation is reduced to equation (11) in a case of $\rho = 1$ and $\phi = t = z = 0$. Increases in the replacement rate ρ and the disability insurance premium rate t encourage firms to exit the labor market, thus lowering labor demand and thereby the wage. In contrast, an increase in the disability insurance payment rate ϕ raises labor demand by encouraging firms' entry, leading to an increase in the wage. For simplicity, we consider the take-it-or-leave-it wage ($\beta = 0$) from now on¹²:

$$w = \frac{[r + \alpha + \delta + \lambda(k)]z}{r + \alpha + \delta + \rho\lambda(k)}. \quad (21)$$

This is the same as the reservation wage. An increase in capital for workplace safety, k lowers the wage. An increase in k lowers the likelihood that an employee is injured or taken ill at the work site and raises the expected value of being employed relative to the value of being unemployed. The state of employment is more attractive, and firms are allowed to capture the whole surplus produced by matched pairs, thus resulting in decreases in the reservation wage and thereby the wage¹³.

¹²The holdup problem does not arise because there is no bargaining power over the wage determination for workers.

¹³If $\rho = 1$ as in the basic model described in Section 2, the wage is reduced to z and does not depend on the amount of capital for workplace safety, k . Because the value for a worker being actively employed and the value of being absent from work due to work-related injury or illness are the same in this case, the likelihood of being injured or taken ill at the work site, which depends on k , does not affect the reservation wage.

From equations (20) and (21), we obtain the value of a job being occupied and active:

$$J(k) = \frac{(r + \alpha + \delta)p}{(r + \delta)[r + \alpha + \delta + \lambda(k)]} - \frac{[(1 + t)(r + \alpha + \delta) + \lambda(k)(t + \rho - \phi)]z}{(r + \delta)[r + \alpha + \delta + \rho\lambda(k)]}. \quad (22)$$

Similarly to Section 2, the nature of equilibrium is characterized by (i) the first-order condition ($V'(k) = 1$), (ii) the free entry condition ($V(k) = k$) and (iii) the steady-state conditions:

(i) the first-order condition

$$\frac{q(\theta)J'(k)}{r + \delta + q(\theta)} - 1 = 0,$$

(ii) the free entry condition

$$\frac{q(\theta)J(k)}{r + \delta + q(\theta)} - k = 0,$$

and (iii) Steady-state conditions

$$\begin{aligned} u &= \frac{\delta}{\delta + \theta q(\theta)}, \\ a &= \left(\frac{\lambda(k)}{\alpha + \delta + \lambda(k)} \right) \left(\frac{\theta q(\theta)}{\delta + \theta q(\theta)} \right). \end{aligned}$$

The first-order and the second-order conditions are presented in the appendix section. The steady-state conditions are the same as those derived in Section 2. The comparative statics studies show the characterizations of the equilibrium in response to the changes of policy parameters.

4.2 Comparative Statics Effects

We next explore the effects of policy parameters (replacement rate, disability insurance payment and premium, and unemployment benefits) on capital for workplace safety and

labor market tightness.

According to the comparative statics analysis, we obtain the following results:

Proposition 5 (a) *replacement rate*

$$\frac{dk}{d\rho} \leq 0 \quad \text{and} \quad \frac{d\theta}{d\rho} \leq 0,$$

(b) *disability insurance payment rate*

$$\frac{dk}{d\phi} < 0 \quad \text{and} \quad \frac{d\theta}{d\phi} > 0,$$

(c) *disability insurance premium rate*

$$\frac{dk}{dt} > 0 \quad \text{and} \quad \frac{d\theta}{dt} < 0,$$

and (d) *unemployment benefit*

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

The appendix section shows analytical details.

(a) *Replacement Rate*

There are two effects of ρ on k and θ to be considered: various direct effects and indirect effects via w . We begin the direct effects. As the replacement rate ρ is higher, firms have to bear the more burden of the recompense for losses from work-related injuries and illnesses ρw , which encourages firms to exit the labor market, lowering θ . Less competitiveness induces firms to buy more capital for workplace safety because it is more likely for firms to meet unemployed workers. At the same time, it implies an increase in the cost that firms would have incurred if accidents had occurred to employed workers at the work sites. Firms thus have more incentives to increase the amount of k to reduce the likelihood of being injured or taken ill at the work site.

The indirect effects show the opposite story. An increase in ρ lowers the wage according to equation (21). As absent employed workers are more sufficiently recompensed for their losses, the state of employment is more attractive for workers. In a case in which workers are allowed to have power over wage bargaining, unemployed workers then accept the lower wage. Firms bear the less burden of the recompense for losses from work-related injuries and illnesses ρw , encouraging firms to enter and thereby raising θ . More severe competitiveness discourages firms from buying capital for workplace safety. A decrease in the wage lowers the cost that firms would have incurred if accidents had occurred, which also discourages firms from buying capital for workplace safety. In addition, an increase in the wage raises the profit, and therefore firms are induced to raise capital for workplace safety because of an increase in the marginal return to capital for workplace safety. Putting differently, an increase in the profit encourages firms' entry, and an increase in the number of rivals lowers the amount of capital for workplace safety.

(b) Disability Insurance Payment Rate

An increase in the disability insurance payment rate ϕ reduces the burden of the recompense for losses from work-related injuries and illnesses, which therefore induces firms to lower the amount of k and encourages firms' entry to the market. An increase in job vacancies due to firms' entry discourages firms from purchasing capital for workplace safety.

(c) Disability Insurance Premium Rate

An increase in the disability insurance premium rate, t implies an increase in the cost that firms would have incurred if accidents had occurred, which thereby induces firms to increase the amount of capital for workplace safety to prevent accidents at the work sites from the value of remaining an occupied job inactive because the worker is absent. Putting differently, an increase in t lowers the profit, which instead induces firms to lower the amount of capital for workplace safety because of a decrease in its marginal return from the value of remaining an occupied active. According to the comparative static analysis shown in Appendix, the former effect is dominant over the latter effect.

Firms are encouraged to exit the labor market by an increase in the recompense for

workplace injury and illness and a decrease in the profit. Less competitiveness allows incumbent firms to provide more chances to meet unemployed workers. *Ex ante* investment in workplace safety is less likely to be idle, therefore providing firms with the incentive to purchase more capital for workplace safety k .

(d) Unemployment Benefit

As seen 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.

The linkage between unemployment benefits and workplace safety is considered here. The comparative statics study shows that capital for workplace safety k is positively or negatively associated with unemployment benefits z . According to equation (21), an increase in z raises the wage. Because the state of unemployment is more attractive for workers, unemployed workers then raises their reservation wage. It implies an increase in the cost that firms would have incurred if their employed workers had been injured or taken ill at the work sites and been absent from work because the compensation is positively proportional to the wage (ρw). Firms have more incentives to increase capital for workplace safety to reduce the likelihood of being injury or taken ill at the work site. However, an increase in the wage implies a decrease in the profit, lowering the expected gain of investing in workplace safety. Therefore, it leads to a decrease in the amount of capital for workplace safety. Putting oppositely, a decrease in the profit discourages firms from entering the labor market, and less competitiveness provides firms with incentives to purchase capital for workplace safety. If the positive effects on k are dominant over the negative effect, the novel result is that the unemployment benefits have a positive effect on capital for workplace safety, implying a decrease in the likelihood of being injured or taken ill at the work site. The unemployment benefits encourage firms to improve working conditions.

(e) Capital and Scale Effects

How do these policy parameters affect the unemployment rate and the fraction of workers who are absent from work because of work-related injuries or illnesses? The total

derivatives of equation (14) are taken with respect to $x = \{\rho, \phi, t, z\}$:

$$\frac{du}{dx} = \underbrace{\left\{ -\frac{\delta}{[\delta + \theta q(\theta)]^2} \right\}}_{-} \left(\frac{\partial \theta q(\theta)}{\partial \theta} \right) \left(\frac{d\theta}{dx} \right),$$

and

$$\begin{aligned} \frac{da}{dx} &= \underbrace{\left(\frac{(\alpha + \delta)\lambda'(k)}{[\alpha + \delta + \lambda(k)]^2} \right)}_{-} \left(\frac{\theta q(\theta)}{\delta + \theta q(\theta)} \right) \left(\frac{dk}{dx} \right) \\ &\quad + \underbrace{\left(\frac{\lambda(k)}{\alpha + \delta + \lambda(k)} \right)}_{+} \left(\frac{\delta}{[\delta + \theta q(\theta)]^2} \right) \left(\frac{\partial \theta q(\theta)}{\partial \theta} \right) \left(\frac{d\theta}{dx} \right), \\ x &= \{\rho, \phi, t, z\}. \end{aligned}$$

Comparative statics effects are summarized in Table 1. The scale effects of the disability insurance premium rate t and unemployment benefits z are unambiguously positive on the unemployment rate u but negative on the fraction of absent employed workers a . The disability insurance payment rate ϕ has the opposite scale effects on u and a , respectively. The replacement rate ρ has ambiguous scale effects on both u and a .

Table 1: Summary of Comparative Statics Effects

		(a) Replacement Rate	(b) Disability Insurance Payment Rate	(c) Disability Insurance Premium Rate	(d) Unemployment Insurance
Capital Effect	a	?	+	-	?
Scale Effect	a	?	+	-	-
	u	?	-	+	+

The capital effect of ϕ on the fraction of absent employed workers a is unambiguously positive through an decrease in capital for workplace safety k . The opposite capital effect of t is then obtained on a . The capital effects of ρ and z are ambiguous on a because it is unclear whether firms raise or lower the amount of capital for workplace safety in response to increases in these parameters.

5 Simple Empirical Evidence

In this section, we attempt to show that, although indirectly, implications of a relationship between unemployment and the number of work-related injured workers are supported by simple empirical studies. Because the amount of capital for workplace safety purchased by firms cannot be observed, there is no way but the capital effect is identified indirectly from a comparison of the effects of labor productivity on unemployment and the number of work-related injured workers.

For visual inspections, we compare relative variations of unemployment rate, the number of workers who have to be absent from work for non-fatal injury to the labor force, and labor productivity per person with respect to the corresponding trends detrended by the Hodrick and Prescott filter method. Figures 1 and 2 display relative deviations of these variables from their trends, using time-series data from two countries, the US and Japan, and Table 2 shows correlation coefficients of these variables over the whole sample period and by sub-periods.

Table 2: Correlations of Unemployment Rate, Labor Productivity and Fraction of Injured Workers

	unemployment vs. injury	unemployment vs. productivity	injury vs. productivity
US overall	-0.790	-0.906	0.800
Japan overall	-0.484	-0.942	-0.480
1980-1988	-0.820	-0.981	0.812
1989-1995	0.556	-0.856	-0.129
1996-2006	-0.784	-0.923	0.679

Figure 1 shows graphs using the data from the US covering from 1980 to 2001. The data of unemployment rate and the labor force are obtained as usual from the *Labor Force Survey*, the US Department of Labor, and the flow rate of work-related injured workers is defined by the number of non-fatal reported injuries occurred in the private sector divided by the labor force where the data of non-fatal reported injuries are obtained from the *Labor-Related Establishment Survey*, the US Department of Labor.

The first graph of Figure 1 displays that the unemployment rate and the flow rate of work-related injured workers are negatively correlated over the sample period (-0.790

from Table 2). The second graph compares relative deviations of the unemployment rate and labor productivity defined by GDP per employed person evaluated at the 1990 US\$ at PPP from *KILM*, ILO. As one would expect, the correlation between these variables is negative over the sample period (-0.906 from Table 2), which strongly supports a view that productivity improvement raises job opportunities, thereby lowering the unemployment rate. The third graph of Figure 1 makes the same comparison of the relative deviations of labor productivity and the flow rate of work-related injured workers. The correlation between labor productivity and the flow rate of work-related injured workers is positive over the sample period (0.800 from Table 2); that is, as productivity improved, the flow rate of work-related injured workers had risen. These results imply that the scale effect of labor productivity is dominant over the capital effect: as labor productivity improves, more jobs are created, and therefore employment rate rises, which leads to an increase in the number of workers who become injured. We predict that an increase in the number of work-related injured workers is attributable mainly to the larger employment size in the US.

Figure 2 shows relative deviations of the variables using the Japanese data from 1980 to 2006. We observe different patterns in movements of the deviations between the period after the burst of the bubble economy (the late 1980s and the early 1990s) and other periods. The data source for unemployment rate and the labor force is the *Labour Force Survey*, the Japanese Ministry of Internal Affairs and Communications (MIC). The flow rate of work-related injured workers is defined by the number of non-fatal injury workers who become absent from work for four days or more, divided by the labor force. The data of non-fatal injury cases come from the *Labour Inspectorate Records*, the Japanese Ministry of Health, Labour and Welfare (MHLW).

The correlations between the unemployment rate and the flow rate of work-related injured workers except the stagnation period after the collapse of the bubble economy (from the late 1980s to the mid 1990s) are similar to that of the US; that is, these two deviations moved in the opposite direction. On the other hand, an interesting observation is that these relative deviations moved in the same direction during the stagnation

period after the burst of the bubble economy, implying a positive correlation between the unemployment and the flow rate of work-related injured workers. The same results are confirmed from Table 2; that is, the correlation coefficients on 1980-1988 and 1996-2006 are negative (-0.820 and -0.784), but the one on the period of economic slowdown after the collapse of the bubble economy (1989-1995) becomes positive (0.556). Labor productivity, defined in a similar way with that of the US from the same data source, and the unemployment rate move oppositely over the sample period, which is the same as in a case of the US. The correlation between labor productivity and the flow rate of work-related injured workers is different during the period of economic slowdown after the burst of the bubble economy from during the other periods; that is, as labor productivity improved, the flow rate of work-related injured workers increased as well before the late 1980s and after the mid 1990s, but the opposite pattern is seen following the collapse of the bubble economy. Table 2 exhibits that the correlation coefficients on 1980-1988 and 1996-2006 are positive (0.812 and 0.679), but that the one is negative between 1998 and 1995 (-0.129).

This implies that similar to the US, the scale effect is dominant except the period of weak economy after the burst of the bubble economy, but during which the capital effect is dominant over the scale effect. We predict that increasing productivity encouraged firms to purchase more capital for workplace safety to reduce the number of work-related accidents following the collapse of the bubble economy. It might be interrupted that the number of work-related injured workers would rather be determined by the amount of capital for workplace safety than by the employment size from the late 1980s to the mid 1990s.

We estimate equations for a flow rate of work-related injured workers and the unemployment rate to reinforce the results obtained from visual inspections. The purpose of this empirical works is to, although indirectly, extract the capital effect in the sense that productivity improvement encourages firms to purchase capital for workplace safety, leading to a decrease in the number of work-related injured workers.

Tables 3 and 4 present empirical results from the US and Japan, respectively. The

AR(1) method is used for any estimations because the null hypothesis of no autocorrelation is significantly rejected. As the independent variables for the estimate of a flow rate of work-related injured workers, the one-period lagged unemployment rate, the one-period lagged productivity and a time trend term are chosen. To control simultaneous bias, the one-period lagged variables are used here. Inclusion of the one-period lagged unemployment rate allows us to control the scale effect of productivity via the unemployment rate, which means that the coefficient on the one-period lagged productivity represents the capital effect on the flow rate of work-related injured workers. To explore the scale effect of productivity, the unemployment rate is estimated using the one-period lagged productivity.

Table 3: Estimates of Growth Rates of Work-Related Injured Workers and the Unemployment Rate (US)

	(1)		(2)	
	AR(1)		AR(1)	
	ln(injury rate)		ln(unemployment rate)	
	Coef.	Std. Err.	Coef.	Std. Err.
ln(unemployment rate(-1))	0.126	(0.239)	-	(-)
ln(productivity(-1))	1.618	(1.478)	-5.449*	(0.703)
Trend	-0.043	(0.026)	0.084*	(0.015)
Constant	-19.283	(13.960)	50.938*	(6.887)
	Value	P-value	Value	P-Value
DW Statistic	0.976		0.579	
Alt. DW Statistic (F value)	4.764	(0.044)	10.498	(0.005)
Breusch-Godfrey (F-value)	4.818	(0.043)	8.017	(0.012)
F value	250.25	(0.000)	232.54	(0.000)
R ²	0.978		0.963	
Sample	21		21	

* 1%, ** 5%, *** 10% significant.

According to the first column of Table 3, the coefficient on productivity is positive and insignificant, which implies that the capital effect is trivial in the US. This result is consistent with the visual inspection from Figure 1. Looking at the second column, productivity has a significantly negative impact on the unemployment rate, which is the one we would expect from Figure 1. However, the impact of the unemployment rate on the flow rate of work-related injured workers is statistically insignificant, so I am afraid to say that the capital effect of productivity through a channel of the unemployment rate

is weak on the flow rate of work-related injured workers.

Table 4: Estimates of Growth Rates of Work-Related Injured Workers and the Unemployment Rate (Japan)

	(1)		(2)	
	AR(1) ln(injury rate)		AR(1) ln(unemployment rate)	
	Coef.	Std. Err.	Coef.	Std. Err.
ln(unemployment rate(-1))	-0.278*	(0.060)	-	(-)
ln(productivity(-1))	-1.518*	(0.211)	-3.628*	(0.651)
Trend	-0.007	(0.006)	0.103*	(0.016)
Constant	8.143*	(1.837)	30.551*	(6.189)
	Value	P-value	Value	P-Value
DW Statistic	1.083		0.358	
Alt. DW Statistic (F value)	5.637	(0.027)	34.239	(0.000)
Breusch-Godfrey (F-value)	5.502	(0.029)	15.829	(0.001)
F value	2244.34	(0.000)	157.81	(0.000)
R ²	0.997		0.932	
Sample	26		26	

* 1%, ** 5%, *** 10% significant.

Results are different for Japan from for the US. According to the first column of Table 4, the coefficient on productivity is significantly negative; that is, productivity improvement lowers a flow rate of work-related injury workers. This result is consistent with the theoretical implication of the capital effect described in the previous section. From the second estimation, productivity has a significantly negative effect on the unemployment rate, and in addition, the impact of unemployment is significantly negative on the flow rate of work-related injured workers. These results imply that the scale effect of productivity through a channel of unemployment is significantly positive on the flow rate of work-related injured workers. Productivity improvement not only created more job vacancies to enlarge the employment size but also induced firms to purchase more capital for workplace safety to reduce the probability of losing a productive worker due to work-related injury. This mechanism operates both an increase and decrease in the flow rate of work-related injured workers.

6 Concluding Remarks

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

By incorporating firms' decisions on the amount of capital for workplace safety in a search and matching model, we investigated the relationship between unemployment and the incidence of work-related injury or illness. Productivity improvement encourages firms' entry and then raises labor market tightness. It lowers the unemployment rate but instead raises the employment rate, including the fraction of absent employed workers. This scale effect implies a negative relationship between the unemployment rate and the fraction of absent employed workers. However, productivity improvement changes firms' behavior toward a determinant of the amount of capital for workplace safety. Potential firms are induced to enter the market as productivity improves, which lowers the likelihood that firms meet unemployed workers. Firms are thereby discouraged from purchasing capital for workplace safety *ex ante*. On the other hand, it is possible that productivity improvement induces firms to buy more capital for workplace safety because of an increase in the opportunity cost of losing workers due to work-related injuries or illnesses. This capital effect determines the distribution of employed workers between active and absent employed workers but does not affect the unemployment rate. The sign of the relationship between the unemployment rate and the flow rate of absent employed workers depends on which is more dominant, the scale effect or the capital effect. The determinant of the amount of capital for workplace safety helps provide an explanation about the puzzling results regarding the relationship between the unemployment rate and the number of absent employed workers who are injured or taken ill suggested by Ussif (2004).

Using the time-series data from the US and Japan, the empirical exercises showed that the scale effect had been dominant over the capital effect over the sample period in the US; that is, the correlation between unemployment rate and a flow rate of work-related injured workers is negative, but that the one turns out to be negative only from

the late 1980s to the mid 1990s, following the collapse of "Bubble Economy" in Japan. Additionally, to distinguish these two effects, we estimated equations for the flow rate of work-related injured workers and the unemployment rate. In a case of Japan, as we would expect, productivity improvement negatively affects the number of worked-related injuries but yields a positive effect on it through a channel of the unemployment rate.

We now briefly discuss social efficiency. According to this model setting, firms buy capital for workplace safety *before* meeting workers in their search activity, and therefore it is well-known that *ex ante* investment in workplace safety causes a hold-up problem as mentioned by Acemoglu and Shimer (1999). It is expected that the optimal capital level for workplace safety in the decentralized environment is lower than the one solved by the social planner¹⁴. It implies that the enforcement of mandates of workplace safety by OSHA is justified to improve social welfare in an environment where a hold-up problem arises.

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¹⁴The hold-up problem does not arise in a case of *ex post* investment in workplace safety. Because there still exists a search externality, however, the optimal amount of capital for workplace safety solved in the model with *ex post* investment is not usually socially efficient.

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Appendices

Comparative Statics Effect (Section 3)

In this appendix, we use comparative statics analysis to explore the effects of productivity p on capital for workplace safety k and labor market tightness θ , using the first-order condition (equation (13)) and the free entry condition (equation (12)). The comparative statics system is given by:

$$\begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} \frac{dk}{dp} \\ \frac{d\theta}{dp} \end{bmatrix} = \begin{bmatrix} B_1 \\ B_2 \end{bmatrix},$$

where:

$$A_{11} = \left[-\frac{(1-\beta)(r+\alpha+\delta)p}{r+\delta} \right] \left[\frac{\lambda''(k)(r+\alpha+\delta+\lambda(k)) - 2(\lambda'(k))^2}{(r+\alpha+\delta+\lambda(k))^3} \right] \leq 0$$

from the second-order condition,

$$A_{12} = -\beta + \frac{(r+\delta)q'(\theta)}{[q(\theta)]^2} < 0,$$

$$A_{21} = -\frac{(1-\beta)(r+\alpha+\delta)\lambda'(k)p}{(r+\delta)(r+\alpha+\delta+\lambda(k))^2} + \beta(1-\theta) - \frac{r+\delta+q(\theta)}{q(\theta)} = 0,$$

from the first-order condition,

$$A_{22} = -\beta k + \frac{(r+\delta)q'(\theta)}{[q(\theta)]^2}k \leq 0,$$

$$B_1 = \frac{(1-\beta)(r+\alpha+\delta)\lambda'(k)}{(r+\delta)(r+\alpha+\delta+\lambda(k))^2} \leq 0,$$

and

$$B_2 = -\frac{(1-\beta)(r+\alpha+\delta)}{(r+\delta)(r+\alpha+\delta+\lambda(k))} \leq 0.$$

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

$$\frac{dk}{dp} = \left(\frac{1}{\nabla_A} \right) \underbrace{\left[-\beta + \frac{(r+\delta)q'(\theta)}{[q(\theta)]^2} \right]}_{-} \underbrace{\left[\frac{(1-\beta)(r+\alpha+\delta)}{(r+\delta)(r+\alpha+\delta+\lambda(k))} \right]}_{+} \underbrace{\left[\frac{\lambda'(k)k + r + \alpha + \delta + \lambda(k)}{r + \alpha + \delta + \lambda(k)} \right]}_{+/-},$$

and

$$\frac{d\theta}{dp} = \frac{A_{11}B_2 - A_{21}B_1}{\nabla_A} \geq 0.$$

As the elasticity of $\lambda(k)$ ($\lambda'(k)k/\lambda(k)$) is much lower, it is more likely that $dk/dp > 0$.

Comparative Statics Effect (Section 4)

The first-order condition and the free entry condition are rewritten as:

$$J'(k) - \frac{r+\delta+q(\theta)}{q(\theta)} = 0,$$

$$\text{and } J(k) - \frac{r + \delta + q(\theta)}{q(\theta)}k = 0,$$

where :

$$J(k) = \frac{(r + \alpha + \delta)p}{(r + \delta)[r + \alpha + \delta + \lambda(k)]} - \frac{[(1 + t)(r + \alpha + \delta) + \lambda(k)(t + \rho - \phi)]z}{(r + \delta)[r + \alpha + \delta + \rho\lambda(k)]}.$$

Since $J'(k) > 0$, we recognize that the marginal value of vacancy is positive for any k ($V'(k) > 0$). If $\lambda''(k)(r + \alpha + \delta + \lambda(k)) - 2(\lambda'(k))^2 > 0$ for any k , $J''(k) < 0$, which is sufficient to show that the optimal capital level maximizes the value of a vacancy.

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

$$\begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix} \begin{bmatrix} dk \\ d\theta \end{bmatrix} = \begin{bmatrix} D_{11} & D_{12} & D_{13} & D_{14} \\ D_{21} & D_{22} & D_{23} & D_{24} \end{bmatrix} \begin{bmatrix} d\rho & d\phi & dt & dz \end{bmatrix},$$

where:

$$C_{11} = J''(k) < 0$$

from the second-order condition,

$$C_{12} = \frac{(r + \delta)q'(\theta)}{[q(\theta)]^2} < 0,$$

$$C_{21} = J'(k) - \frac{r + \delta + q(\theta)}{q(\theta)} = 0$$

from the first-order condition,

$$C_{22} = \frac{(r + \delta)q'(\theta)k}{[q(\theta)]^2} < 0,$$

$$D_{11} = - \left[\frac{\lambda'(k)(r + \alpha + \delta)z}{r + \delta} \right] \left[\frac{t(r + \alpha + \delta + \rho\lambda(k)) + 2\lambda(k)((1 - \rho)t - \phi)}{(r + \alpha + \delta + \rho\lambda(k))^3} \right] \leq 0,$$

$$D_{21} = \left(\frac{z}{r + \delta} \right) \frac{\lambda(k)[t(r + \alpha + \delta) + \lambda(k)(t - \phi)]}{(r + \alpha + \delta + \rho\lambda(k))^2} \leq 0,$$

$$D_{12} = - \frac{\lambda'(k)(r + \alpha + \delta)z}{(r + \delta)(r + \alpha + \delta + \rho\lambda(k))^2} > 0,$$

$$D_{22} = - \frac{\lambda(k)z}{(r + \delta)(r + \alpha + \delta + \rho\lambda(k))} < 0,$$

$$D_{13} = \frac{\lambda'(k)(r + \alpha + \delta)(1 - \rho)z}{(r + \delta)(r + \alpha + \delta + \rho\lambda(k))^2} < 0,$$

$$D_{23} = \frac{(r + \alpha + \delta + \lambda(k))z}{(r + \delta)(r + \alpha + \delta + \rho\lambda(k))^2} > 0,$$

$$D_{14} = \frac{\lambda'(k)(r + \alpha + \delta)((1 - \rho)t - \phi)}{(r + \delta)(r + \alpha + \delta + \rho\lambda(k))^2} > 0,$$

assuming $\phi \neq (1 - \rho)t$,

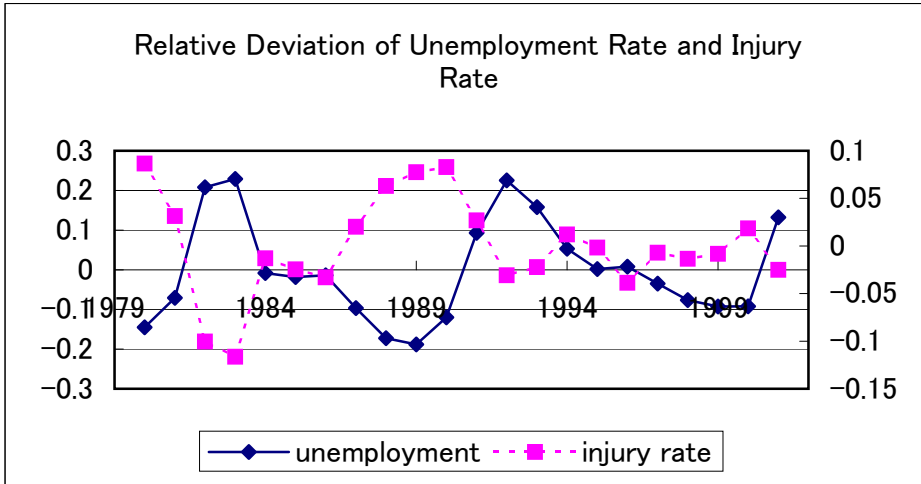
and

$$D_{24} = \frac{(1 + t)(r + \alpha + \delta) + \lambda(k)(t + \rho - \phi)}{(r + \delta)(r + \alpha + \delta + \rho\lambda(k))} > 0,$$

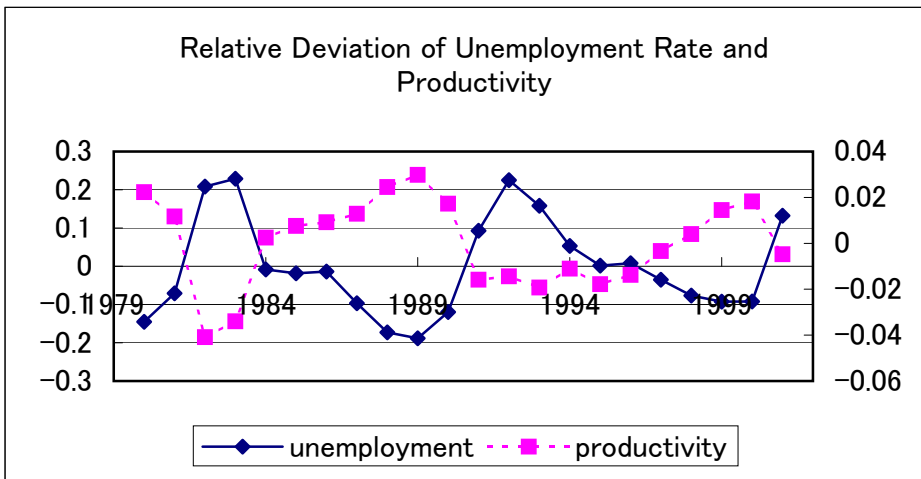
assuming $\phi \neq t + \rho$.

The Jacobian determinant is $\nabla_C \equiv C_{11}C_{22} - C_{12}C_{21} > 0$. We then obtain the implications described in proposition 5.

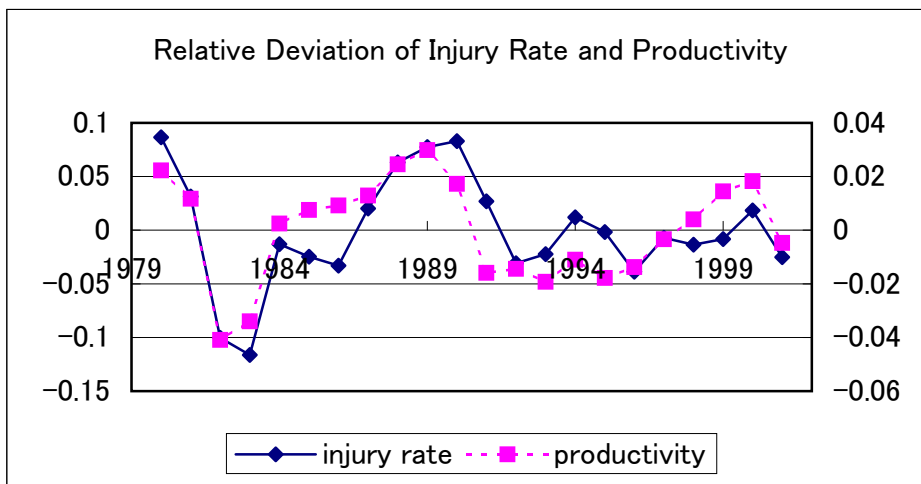
Figure 1 US



The left vertical line measures unemployment rate.
 The right vertical line meaures flow rate of injured workers.

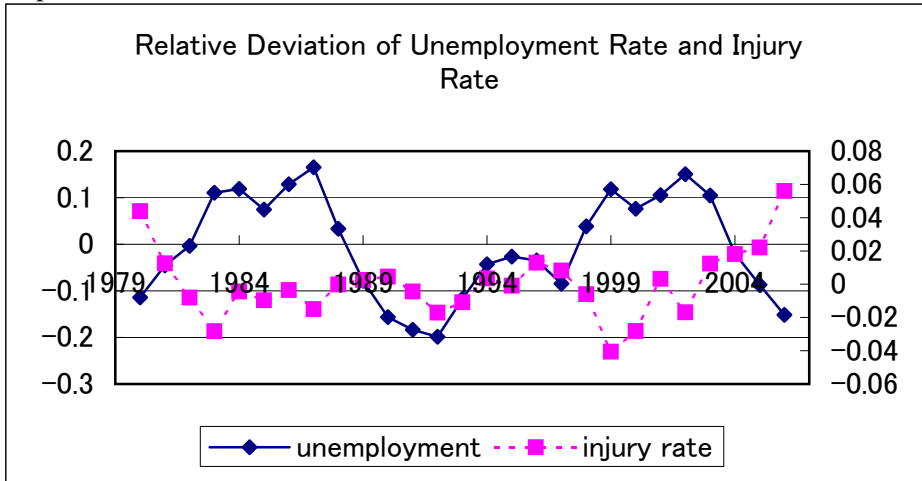


The left vertical line measures unemployment rate.
 The right vertical line meaures labor productivity..

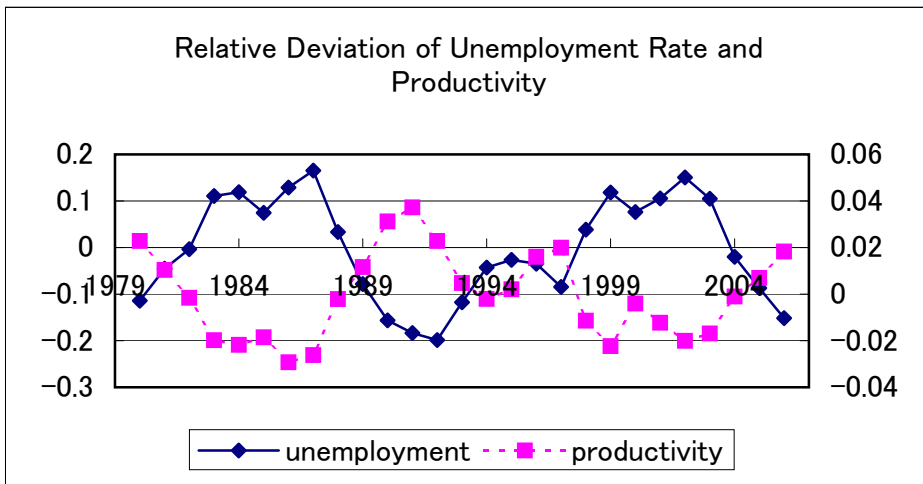


The left vertical line measures flow rate of injured workers..
 The right vertical line meaures labor productivity..

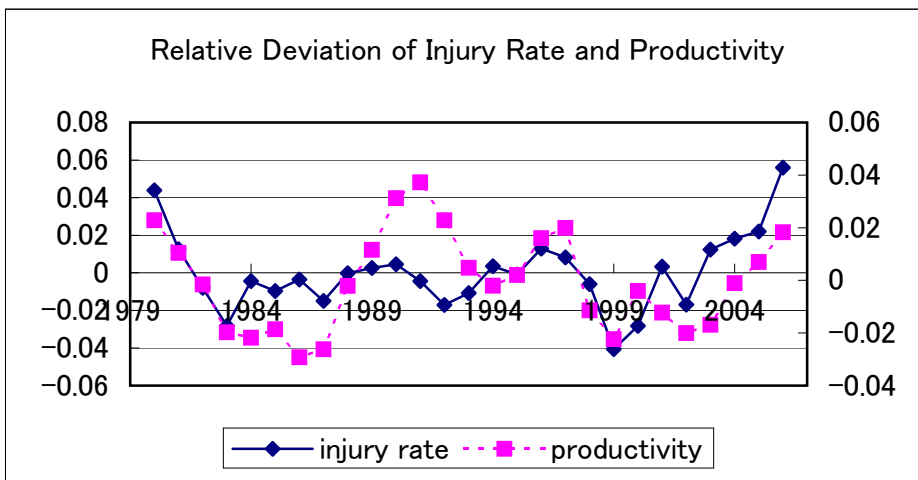
Figure 2 Japan



The left vertical line measures unemployment rate.
The right vertical line measures flow rate of injured workers.



The left vertical line measures unemployment rate.
The right vertical line measures labor productivity..



The left vertical line measures flow rate of injured workers..
The right vertical line measures labor productivity..