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# Are recessions good for workplace safety?

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## Abstract

Empirical evidence shows that in recessions the rate of workplace accidents goes down. This paper presents a theory and an empirical investigation to explain this phenomenon. The theory is based on the idea that reporting an accident dents the reputation of a worker and raises the probability that he is fired. If the unemployment rate is high, a worker faces a big loss when fired and fewer workplace accidents are reported. The empirical investigation concerns workplace accidents in 16 OECD countries. We conclude that cyclical fluctuations in workplace accident rates have to do with reporting behavior of workers and not with changes in workplace safety.

**JEL codes:** I31, J28

**Keywords:** workplace accidents, unemployment

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# 1 Introduction

Workplace accident rates are procyclical, which could indicate that workplace safety increases in recessions. If so, this would be in line with evidence presented by Ruhm (2000) indicating that booms are unhealthy. Ruhm finds a strong relationship between macroeconomic conditions and mortality, which he attributes to hazardous working conditions, the physical exertion of employment, and job-related stress when job hours are extended during short-lasting economic expansions.<sup>1</sup> This explanation for the procyclicality of workplace accident rates has to do with working conditions and concerns workplace safety. In booms the effort level of workers is higher. When employers require high effort levels from their workers, these workers become less careful. Hence the rate of workplace accidents increases. When workers exert less effort, they can take more care and are therefore involved in less accidents. If effort is procyclical, so is the rate of workplace accidents. Consequently, the workplace accident rate is negatively correlated with the unemployment rate. Also in booms more workers are hired than in slumps. If newly hired workers are less experienced and are therefore more likely to be involved in workplace accidents there is an additional explanation a higher accident rate in a boom.

The change in workplace safety is not the only explanation for the cyclicity in workplace accident rates. An alternative explanation is related to the well-known procyclical variation in workers' absenteeism. If unemployment is high, workers fear to lose their job, so conditional on a specific state of their health they are less inclined to stay away from work. If unemployment is low, employers will be more reluctant to fire a worker even in case of frequent absenteeism. So, absence-prone workers are more likely to be dismissed in an economic downturn (Leigh (1985)).

In terms of workplace accidents the idea is that workers are reluctant to report these accidents because they fear (correctly or incorrectly) that employers will hold this against them.<sup>2</sup>

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<sup>1</sup> Ruhm (2000) investigates the relationship between economic conditions and health, using U.S. state specific data. Other possible reasons for the relationship mentioned are that higher employment rates are associated with increases in smoking and obesity, reduced physical activity, and worse diets. Also, the higher incomes associated with good economic times may lead to increases in some risky activities. Ruhm (2001) finds that there is countercyclical variation in physical health while there is some evidence that mental health is procyclical.

<sup>2</sup>OECD (1989) notes that among social and psychological factors which influence workplace accidents statistics that "workers may not report injuries because they fear loss of attendance bonuses, or other personal disadvantages, such as becoming prime candidates for redundancy".

In particular, we assume that workers think that if the firm has to lay off some workers at some future date (say, because of a labor saving innovation or because demand for the industry's products goes down) it will tend to fire workers that have reported accidents in the past. When unemployment is low, being fired does not involve a big loss because it is relatively easy to find a new job. Hence workers are more likely to report an accident when unemployment is low. In contrast, a high unemployment rate makes it harder for a fired worker to find a new job and hence a worker is less likely to report an accident. So we expect that the reporting rate of accidents is low if the unemployment rate is high.

For concreteness, consider the following example. A worker in a factory carries a heavy object. He stumbles and almost drops the object which causes him to strain his back. If the back pain is so severe that he cannot continue to work, he has no choice but to report the accident. He can then go home to recover for a couple of days. If the worker can continue work but the back pain is rather uncomfortable he decides whether to inform his employer or not. Our conjecture is that he is more likely to report the accident if the unemployment rate is low. If his employer would use the accident against him, in the sense that it becomes more likely that he will be fired if the firm needs to shed labor, at least the consequences are not too severe. Similarly, a secretary who feels her fingers tingling faces the choice of stopping to work and go home or continuing and raise the risk of a mouse arm. Our conjecture, again, is that she will continue to work if the unemployment rate is high, until it becomes clear that she does have a problem with her arm and needs rest.

This paper focuses on the question whether a high workplace accident rate in a boom is a true workplace safety phenomenon related to stress or inexperienced workers and thus an indication of workers' health being harmed in prosperous times or whether alternatively a high workplace accident rate in a boom is a spurious phenomenon caused by changes in workers reporting behavior. The two explanations for the cyclicity of workplace accidents are tested empirically. Part of the evidence presented uses the distinction between non-fatal and fatal accidents (see the appendix for more details). The workplace safety explanation predicts that the unemployment rate has a negative effect on workplace accidents. Furthermore, it predicts that working hours have a positive effect on workplace accidents because working longer increases the probability of an accident. This can happen for two reasons. First, working more hours may make workers tired and fatigue raises the probability of injury per hour (or per task). Second, even if the

injury rate per hour (or task) is unchanged, working more hours increases the workers' exposure to this risk of accidents at work. This raises the accident rate (per worker). Also, the change in the employment rate is positively related to the workplace accident rate since an increase in employment coincides with a lot of new hirings while a decrease in employment is related to few new hirings. New hirings tend to be less experienced and hence more prone to have or cause an accident. If workplace safety is the driving force not only the non-fatal accident rate but also the fatal accident rate will exhibit cyclical behavior. The 'reporting' explanation predicts that the unemployment rate is negatively related to the non-fatal workplace accident rate but not to the fatal accident rate because fatal accidents are always reported (if there is a reporting decision at all in this case). Further, as unemployment benefits go up one should expect a smaller effect of the unemployment rate on the non-fatal accident rate.

In our empirical analysis it appears that the unemployment rate is negatively related to the workplace accident rate while working hours and the change in the employment rate have no effect on the workplace accident rate. Furthermore, cyclical behavior is found only for non-fatal workplace accidents. From this evidence and additional sensitivity analyses we conclude that the procyclical behavior of workplace accidents is most likely related to reporting rates and not to actual fluctuations in accidents. From a policy perspective this result implies that when in cyclical downturns the workplace accidents rate goes up there is no urgent need to start worrying about workplace safety nor to start a work safety campaign. Instead, in times of high unemployment safety auditors should encourage people to report (minor) accidents.

The paper is set up as follows. In Section 2 we set the stage by giving an overview of previous studies on absenteeism and workplace accidents. In Section 3 we present a theoretical model that explains the cyclical behavior in reported workplace accidents. Section 4 describes the data on workplace accidents from 16 OECD countries, discusses the statistical model and presents estimation results. Section 5 concludes.

## 2 Previous studies

There are several studies that investigate the cyclical behavior of workplace absenteeism. According to Barmby et al. (1994) the effect of absence behavior on the probability of being fired may act as a worker discipline device. Brown and Sessions (1996) distinguishes between absence

that occurs for valid (i.e. ‘sickness’) and invalid (i.e. ‘shirking’) reasons. According to them little attention has been paid in the economic literature to either the causes or the effects of absenteeism. They analyze absence within the framework of the static neoclassical labor supply model in which a worker has an incentive to absent himself if the level of contractual hours specified by the employer exceeds his desired hours. According to Johansson and Palme (1996) when unemployment increases, shirking or absenteeism decreases. They use a 1981 Swedish micro dataset to investigate the relationship between work absence and county-specific annual average unemployment rates. They find a negative relationship. Johansson and Palme (2002) presents an analysis of panel data showing a declining work absence of Swedish blue-collar workers during a period in which there was a major reform in the income replacement program for short-term sickness and income taxes. It turns out that the cost of being absent significantly affects work absence behavior. The increased cost, rather than the higher unemployment rate, caused the decrease in the work absence rate. According to Arai and Thoursie (2005) procyclical absenteeism might be due to higher sick-rates of marginal workers, or a consequence of procyclical sick-report incentives. They use Swedish data for 14 industries in 3 regions to investigate the correlation between sick rates and the share of temporary contracts. A positive correlation would imply a selection effect, a negative relation would imply a worker incentive effect. The results show that the sick-rate and the share of temporary contracts are negatively and significantly correlated. Finally, Askildsen et al. (2002) use a panel of Norwegian register data over the period 1990-95 to distinguish between two alternative explanations for the cyclicality in absence behavior: disciplining effects of unemployment and changes in the composition of the labor force (when labor is scarce marginal workers who are more prone to be absent are offered jobs). They find that county-specific unemployment rates are negatively related to both the probability of having a sickness spell in a given year and for the duration of absence. They find that this also holds for a subsample of stable workers (those who are in the labor force for a long period). From this they conclude that the selection effect is not causing the cyclical behavior. So, although as far as absenteeism is concerned incentives and composition effects are two competing explanations for cyclical fluctuations the incentive effect seems to be the dominant one.

There are also a number of studies investigating workplace accidents. Kossoris (1938) is a very early reference to the pro-cyclical pattern in accident rates. Schuster and Rhodes (1985)

conclude that there is little evidence of overtime hours being systematically related to injury rate risk. Kniesner and Leeth (1989) presents a numerical simulation, based on data from the early 1970s, to investigate the economic links between labor market outcomes and the workers' compensation insurance system. Their results suggest that the observed positive association between work-related injuries and benefits across states reflects incentives for workers to report injuries rather than that it reflects an economic incentive for employers to invest less in workplace safety. Meyer et al. (1995) uses a "natural experiment" in two American states (Kentucky and Michigan) to compare individuals injured before and after increases in the maximum benefit amount. They find that time out of work increased for those eligible for the higher benefits and remained unchanged for those whose benefits were constant. Hokkanen (1998) uses the frequency of industrial injury rates as an indicator of unobservable labor effort. This idea comes from Shea (1990) who suggests that accidents only occur in the workplace if labor really works. This can happen for two reasons. First, if labor works (hard), workers become tired and fatigue may increase the accident rate per hour (or per task). Thus in recessions when workers perform less tasks per hour or are assigned to non-production activities (maintenance, repairing) the number of accidents per hour should fall which decreases the accident rate (per worker). Second, working more hours increases the likelihood of a work related accident even if the accident rate per hour (task) is unaffected. If firms require more hours worked from employees in booms and less in recessions, then hours worked will be pro-cyclical and the accident rate (per worker) positively correlated with aggregate fluctuations in the economy. Hokkanen does not study injury rates directly but concludes that the injury rate variable that is used as a proxy for unobserved labor effort is significantly related to output in the production function regression, "which is to be expected if true labor effort is pro-cyclical". Shea (1990) suggests that variables such as overtime, hiring and firing rates, the share of non-production workers, and the investment-to-capital ratio may affect the accident rate over the business cycle. What matters for the development of the injury rates are the flows in and out of the labor force, i.e. the hiring and firing rates. Fairris (1998) shows that in U.S., manufacturing injury rates are procyclical. Also, in the 1940s and 1950s injury rates in U.S. manufacturing declined whereas in the 1960s these rates increased. He states that reduced workplace safety due to changes in the institutional arrangements of shopfloor governance is likely to be responsible for this.

### 3 Workplace accidents - theory

This section introduces a model to formalize the relation between cyclical variations in unemployment and workplace accidents. The idea is that reporting accidents affects a worker's reputation and raises the probability that he will be fired. This is especially disadvantageous for the worker if the value of being unemployed is low. Hence in such circumstances one expects fewer accidents to be reported. The value of being unemployed varies with the business cycle. In the empirical analysis we use unemployment as indicator of the cycle because this is the variable suggested by the model below. Further, if unemployment benefits are high in a country, becoming unemployed is not so bad. We show that higher unemployment benefits reduce the effect of the unemployment rate on workers' reporting behavior.

The idea that reporting an accident may raise the probability of being fired is similar to an idea in Barmby et. al. (1994). They introduce an efficiency wage model of absenteeism. Workers shirk in this model by overstating their 'level of sickness' in order to stay at home. To discipline workers, the firm invests in a monitoring technology to verify workers' health status. If an absent worker is found to be fit enough to work, this is seen as shirking and the worker is fired. A difference between absenteeism and our model of accidents is the following. Absenteeism is observable, while the motivation for being absent (sickness or laziness) is not (directly observable). In our model, an accident is not observable by the firm unless it is reported by the worker. Once the accident is reported, the firm can determine the damage caused by the accident and compensate the worker accordingly. This can, for instance, take the form of days off (leisure) for the worker to allow him to recover.

The idea that not all accidents are reported and that there is a decision involved in reporting an accident has been documented by other authors. For instance, Glazner et al. (1998) use a 'natural experiment' to identify underreporting of accidents in the construction industry. And Biddle et al. (1998) show evidence that 'a significant number of employees with occupational diseases (...) "tough it out" or "work through" the problem'. That is, although these workers could have decided to report the problem, they instead kept on working without informing the firm.

As we point out discussing the data below, it does not matter who formally reports the



accidents to the data source.<sup>3</sup> The employer will not know about the accident unless the worker involved reports the accident. As we show below, it is optimal for the employee to report very severe accidents. These are probably also the type of accidents that are very hard, if not impossible, to hide.

Consider the following model of workplace accidents. Each worker has an exogenous probability  $\phi$  of experiencing a workplace accident. We assume that  $\phi$  does not vary over the business cycle (unlike other models of workplace accidents discussed above). Yet, the model predicts that reported accidents do vary over the business cycle. The damage (in terms of utility) of the accident to the worker is denoted by  $\alpha \geq 0$ , which is a random variable with density function  $f(\cdot)$  and distribution function  $F(\cdot)$ . After the accident has happened, a worker decides whether to report it or not. If he reports the accident, the worker gets a compensation  $\gamma(\alpha)$  which depends on the damage the worker incurred. It seems reasonable to assume that  $\gamma'(\alpha) \geq 0$ . However, reporting also has a stigma effect: the firm may conclude that workers who report an accident may be more accident prone than workers who have never reported an accident. Hence, if the firm has to fire some workers (say, in a downturn) workers who have reported an accident are more likely to be fired than workers who never reported an accident since such a report is a signal that the worker is likely to have more accidents in the future. Alternatively, to the extent that a reported accident is costly to the firm (because the worker is allowed to stay at home for a couple of days), the firm may want to implicitly discourage reporting of accidents by giving the impression that workers who have reported in the past are more likely to be fired once the firm has to shed labor. In other words, although the firm understands that workers are identical in terms of accident-proneness (hence there is no direct reason to fire someone who has had an accident in the past), it can still be profitable to create a reputation for firing people that have reported an accident. In this way, the firm discourages the reporting of accidents. Even if this is not really the case, our story still goes through as long as workers believe that their firm may behave in this way. Our model focuses on the dynamics of accidents reports. Therefore we will not model workers as differing in accident proneness nor the reputation value for the firm to be seen as tough on accidents.

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<sup>3</sup>The exception is data taken from a household survey asking working family members whether they have had a work related accident in the past year. In such a survey workers may report an accident that they did not report at their firm. We have no such data. Our prediction would be that in such a data set accidents are not cyclical.

Using a dynamic model of the labor market in the vein of Mortensen and Pissarides (1999), let  $V_E(t)$  denote the value of having a job at time  $t$  while the worker has never reported an accident at its current employer.<sup>4</sup> We assume that  $V_E(t)$  is determined by the following Bellman equation

$$\begin{aligned} \rho V_E(t) = & w + \phi \int_0^{+\infty} [-\alpha + \max\{\gamma(\alpha) + V_A(t) - V_E(t), 0\}] f(\alpha) d\alpha \\ & + \delta_E (V_u(t) - V_E(t)) + \dot{V}_E(t) \end{aligned} \quad (1)$$

where  $\rho$  is the discount rate,  $V_A(t)$  is the value of employment once a worker has reported an accident,  $V_u(t)$  is the value of being unemployed and  $\delta_E$  is the (flow) probability of being fired. Thus, the value of being employed at the firm equals the sum of four terms: the wage  $w$  received while being employed, the (flow) probability that an accident happens (see below), the firing probability  $\delta_E$  and the change in the value of  $V_E(t)$ .

We assume that either the wage is determined by Nash bargaining<sup>5</sup> or that workers are free to quit the job. Assuming that workers have some bargaining power, both imply that  $V_E(t) - V_u(t) > 0$ . Below we specify a matching model for unemployment. In that case, the inequality  $V_E(t) - V_u(t) > 0$  holds if  $w - \phi \int_0^{+\infty} \alpha f(\alpha) d\alpha$  exceeds the unemployment benefit level  $b$ .

We view equation (1) as a differential equation with an exogenous time path for  $V_u(\cdot)$ . The time path for  $V_A(\cdot)$  is derived below. The time path for  $V_u(\cdot)$  can be perfectly predicted by agents<sup>6</sup> and we assume that  $|V_u(\cdot)| < M$  for some  $M > 0$ . Below we consider a search and matching imperfection in the labor market which implies that  $\frac{b}{\rho} < V_u(t) < \frac{w + \int_0^{+\infty} \gamma(\alpha) f(\alpha) d\alpha}{\rho}$ , where  $b$  is the unemployment benefit level. Hence, for  $M = \frac{w + \int_0^{+\infty} \gamma(\alpha) f(\alpha) d\alpha}{\rho}$ , we indeed find that  $|V_u(t)| < M$  for all  $t$ .

Next, consider the worker's response after an accident happens. The accident gives him the disutility  $\alpha$  of the damage. Then the worker decides whether to report the accident or not. If

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<sup>4</sup> We assume that when a worker is fired and finds a new job, his new employer does not know whether he has reported accidents at his previous employers.

<sup>5</sup> There is an issue here whether the Nash bargained wage is continuously renegotiated in response to, for instance, changes in  $V_u(t)$  over time. For notational simplicity we assume that  $w$  is constant over time, however all results below go through if  $w$  would be indexed by  $t$  as well.

<sup>6</sup> If this were not the case, the analysis would be done in terms of expected values for unemployment, employment etc. For the problem we are considering, nothing would be gained by working in terms of expected values.

he does not report the accident, he gets no compensation nor a stigma. If he does report the accident, he gets the compensation  $\gamma(\alpha)$  from the firm, but also has the reputation of someone who has reported an accident. That is, his continuation pay off is  $V_A(t)$  instead of  $V_E(t)$ .

We assume that the Bellman equation for someone who has reported an accident equals

$$\rho V_A(t) = w + \phi \int_0^{+\infty} [-\alpha + \gamma(\alpha)] f(\alpha) d\alpha + \delta_A (V_u(t) - V_A(t)) + \dot{V}_A(t) \quad (2)$$

where  $\delta_A$  is the probability that a worker who has reported an accident will be fired. As mentioned above, we assume that workers who have reported an accident are more likely to be fired (when the firm has to fire employees) than workers who have reported no accidents. Hence, we assume that  $\delta_A > \delta_E$ . This is our reduced form modeling of the idea that (workers think that) firms are more likely to fire workers who have reported an accident. Note that this does not imply firms firing workers on the spot after an accident (which would be illegal). It is only that in a future state of the world where the firm has to fire employees (workers think that) the firm is more likely to fire someone who has reported an accident in the past. Hence, a worker's expected remaining tenure with the firm goes down after reporting an accident.

We also assume that reporting an accident has no effect on a worker's wage, which would indeed be illegal in most if not all countries in our dataset. Next, we suppose, for simplicity, that reporting more than one accident instead of just one accident has no effect on the probability of being fired. This is just to simplify notation. All the results below go through as long as the probability of being fired  $\delta_A$  is nondecreasing in the number of accidents reported. Since we assume that  $\delta_A$  does not further increase by reporting more than one accident, it is optimal for the worker to report each accident after the first one and receive the compensation  $\gamma(\alpha)$  from the firm.

Since  $V_u(t) - V_E(t) < 0$  and because a worker who has not reported an accident yet can always mimic the behavior of a worker who has already reported an accident, we find that  $\delta_A > \delta_E$  implies  $V_E(t) > V_A(t)$ . In particular, comparing equations (1) and (2) term by term, we see the following. The wage is the same in both cases. An employed worker has the option to report all accidents (but may do better to keep silent about minor accidents) and hence the term with the integral is at least as big in equation (1) as in equation (2). Finally, the higher value for  $\delta$  in equation (2) leads to a more negative term due to the probability of unemployment. Hence, no matter how  $V_E$  and  $V_A$  vary over time, it is always the case that  $V_E(t) > V_A(t)$ .

It is now straightforward to see that a worker's optimal reporting strategy takes the following form. Report an accident if and only if  $\gamma(\alpha) - (V_E(t) - V_A(t)) \geq 0$ . Since by assumption  $\gamma'(\alpha) \geq 0$ , for given  $V_E(t) - V_A(t)$  only accidents  $\alpha \geq \bar{\alpha}$  are reported. Hence, conditional on  $V_E(t) - V_A(t)$  the probability that an accident is reported equals  $\phi(1 - F(\bar{\alpha}))$ . Next note that as  $V_E(t) - V_A(t)$  becomes smaller, the loss of reporting an accident becomes smaller, and hence more accidents will be reported.

So the crucial question is how the path of  $V_u(\cdot)$  affects the difference  $V_E(\cdot) - V_A(\cdot)$ , because that is the channel through which the unemployment rate affects the number of accidents reported. In proposition 1 in appendix 2 we prove formally the following intuitive result. A higher value of  $V_u$  reduces  $V_E - V_A$  and hence leads to more accidents being reported. The intuition is that with high  $V_u$ , the stigma of having reported an accident (and associated higher probability of being fired) is not so bad since becoming unemployed is not so bad. Hence, more accidents get reported.

Hence the channel in the reporting explanation is from unemployment  $u(t)$  to the value of being unemployed  $V_u(t)$  and then to the accidents that are reported  $\alpha > \bar{\alpha}$ . The working conditions explanation takes reporting as given and assumes that the probability of an accident  $\phi$  is affected by the business cycle. In particular, it assumes that  $\phi$  rises with employment and hours worked and falls with unemployment. As employment rises, new unexperienced workers are hired which are more likely to cause accidents involving themselves and others. As employment falls, not many inexperienced workers are hired, reducing the probability of an accident. Further, in a boom unemployment is low and workers work harder and more hours. This may lead them to become less careful and hence more accidents happen. These working conditions explanations are true for all  $\alpha$ . Thus one would expect the same cyclicity in non-fatal and fatal accidents. In contrast, with the reporting explanation fatal accidents (high  $\alpha$ ) are always reported irrespective of the state of the cycle. The reporting of non-fatal accidents (lower  $\alpha$ ) depends on the state of cycle via the value of being unemployed  $V_u$ .

Up until now, we have analyzed the effects of  $V_u$  on the reported number of accidents. However, in the empirical analysis we look at the effects of the business cycle, proxied by unemployment rate  $u(\cdot)$ , on the number of reported accidents. The remainder of this section links the development of  $u(\cdot)$  to the development of  $V_u(\cdot)$ . In order to do this, we work with a search and matching model in the labor market. In particular, we assume that the development

of  $V_u(\cdot)$  is determined by the following differential equation

$$\rho V_u(t) = b + q(u(t)) [V_E(t) - V_u(t)] + \dot{V}_u(t) \quad (3)$$

where  $b$  is the unemployment benefit level and  $q(\cdot)$  denotes the probability that an unemployed worker is matched with job. We assume that  $b < w + \phi \int_0^{+\infty} [-\alpha + \gamma(a)] f(\alpha) d\alpha$  which implies that a worker is better off having a job than remaining unemployed. Since we assume that a new employer does not know whether the worker has reported an accident in his previous job, the value of a new job is  $V_E$  irrespective of the history of the worker. We view this as a differential equation determining  $V_u(t)$  as a function of the exogenous time path for unemployment  $u(t)$ , where  $V_E(t)$  is determined by equation (1).

We assume that the probability of getting a job is decreasing in the unemployment level  $u(t)$ , that is  $\frac{dq(u(t))}{du(t)} < 0$  for all  $t$ . This implies that the value of being unemployed  $V_u$  falls with the unemployment level, since a higher unemployment level increases the expected duration of the unemployment spell. The way we think of the function  $q(\cdot)$  is as a matching probability, where the number of matches each period equals  $m(u(t), v(t))$  for some matching function  $m(\cdot, \cdot)$  and where  $v(t)$  denotes the number of vacancies posted at time  $t$ . Hence the probability of being matched at time  $t$  for an unemployed worker equals  $\frac{m(u(t), v(t))}{u(t)}$ . We do not model the number of vacancies  $v(t)$  but assume that a Beveridge curve exists (see for example Nickell et al. (2003)). That is,  $v(t)$  is negatively correlated with  $u(t)$ . Thus we write  $q(u(t)) = \frac{m(u(t), v(u(t)))}{u(t)}$ , with  $q'(u) < 0$ .

Hence, as unemployment goes up, the value of becoming unemployed goes down and therefore less accidents are reported. Note that it is unemployment  $u(\cdot)$  that affects the reporting of accidents, not employment. Although employment and unemployment may be correlated, the employment rate does not (directly) affect the value of being unemployed. Thus the theory points to unemployment as the relevant measure of the business cycle. In contrast, a theory based on the idea that in a boom new -inexperienced- workers are hired who are more likely to cause or be involved in an accident predicts that accidents are related to the employment rate (in particular, the change in the employment rate) as relevant variable summarizing the business cycle. As shown below, we do not find the latter effect in the data.

We can also show the following result. As unemployment benefits go up, the value of becoming unemployed varies less with the unemployment rate (unemployment benefits work as an insurance). Therefore one should expect reported accidents to vary less pronounced with

unemployment as the unemployment benefits are higher. The proof of this result can be found in the appendix.

**Lemma 1** *If  $V_E(t) - V_u(t)$  is linear (or concave) and decreasing in  $V_u(t)$  then it is the case that  $\frac{dV_u}{du} < 0$  increases with  $b$ ; put differently,*

$$\frac{d\left|\frac{dV_u}{du}\right|}{db} < 0.$$

For instance, if workers and firms Nash bargain about the wage it is the case that  $V_E - V_u$  is linear and decreasing in  $V_u$ . To see this, consider the case where workers and firms bargain about the value of being employed  $V_E$  (determined by the wage  $w$ ). Then  $V_E$  solves

$$\max_{V_E} (V_E - V_u)^\beta (Y - V_E)^{1-\beta}$$

where  $V_u$  is the fall back position of the worker,  $Y$  is the discounted expected output produced by the worker. We assume (as usual) that there is free entry into vacancy creation and hence the fall back position of the firm equals 0 (zero). It is routine to verify that in this case  $V_E - V_u$  is linear and decreasing in  $V_u$ . Thus we have in this case that higher unemployment benefit levels make the value of being unemployed  $V_u$  less dependent on the unemployment rate  $u$ . This insurance role of unemployment benefits also implies that the number of accidents reported should depend less on the unemployment rate as unemployment benefits are higher.

Countries can differ in a number of aspects that are not discussed here (and for which we have no variables in the empirical analysis). For instance, employment protection legislation differs between countries and this will affect the workers' reporting decisions. The better employment protection is in a country, the more accidents one would expect a worker to report. This is true, but this mainly affects the level of accident reports. We would still expect the cyclical behavior of accident reports to the extent that employment protection is not perfect. Hence in countries with strong employment protection legislation, the cyclical pattern in accident reports (and hence the accident rate) will not disappear, although the amplitude may be smaller.

## 4 Workplace accidents across the OECD

According to the European Statistics on Accidents at Work an accident at work is defined as a "discrete occurrence in the course of work, which leads to physical or mental harm."<sup>7</sup> Workplace accidents are a common phenomenon. In the EU for example in 1998 there were 4.7 million occupational accidents leading to more than 3 days' absence from work, which is equivalent to an accident rate - i.e. the probability that a worker is involved in a workplace accident - of 4.1%. The total number of accidents, including those which did not involve absence from work amounted to 7.4 million, equivalent to an accident rate of 6.4%. A fatal accident is defined as an accident, which leads to the death of a victim within one year (after the day) of the accident. The incidence of accident-related deaths was 5.0 per 100,000 workers. Finally, annually around 150 million working days are lost due to non-fatal accidents, which is about 0.5% of total working time (European Agency for Safety and Health at Work (2001)).

### 4.1 Data

There are clear differences in the ways in which countries define and register workplace accidents (see also OECD (1989) for an overview). Differences refer for example to the minimum number of working days lost to the accidents, the severeness of the accidents, whether or not commuting accidents are included. Our point of departure is that a firm does not know about an accident unless it is reported by the employee(s) involved. Firms may have an incentive to underreport accidents to avoid further probes by workplace safety inspectors. However, there is no reason why this should be cyclical.

There are large differences between countries in workplace accidents, as shown in Table 1. In 1990 there were 115,000 workplace accidents in Belgium of which 106 were fatal, in France there were 760,000 workplace accidents of which 1213 were fatal, in Germany there were 1.9 million workplace accidents of which 1712 were fatal, while in the US there were 3.1 million workplace accidents of which almost 3000 were fatal. The share of fatal accidents as a percentage of total workplace accidents ranges from a low 0.07% in Finland and Portugal to as high as 2.4% in

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<sup>7</sup>This includes cases of acute poisoning and willful acts of other persons but excludes self-inflicted injuries and commuting accidents. "In the course of work" means whilst engaged in an occupational activity or during the time spent at work. This includes cases of road traffic accidents in the course of work.

Ireland. The latter high share is also because the number of non-fatal workplace accidents in Ireland is rather low. The appendix provides more details about the data.

Figure 1 shows the evolution of (non-fatal) workplace accident rates and unemployment rates for the 16 OECD countries in our sample. As shown in many but not all countries there is a downward trend in workplace accident rates. Countries where there is no clear downward trend are Denmark, Ireland and Spain. Nevertheless, for some countries it is clear that there is an inverse relationship between workplace accidents and unemployment. For example the increase in unemployment rate in the early 1990s in Canada, Finland and Sweden is accompanied by a major drop in the workplace accident rate. In Ireland the major drop in unemployment rate since the mid 1990s is accompanied by a strong increase in the workplace accident rate. In countries like Denmark, France, Italy, Portugal and Spain there are several upturns and downturns in the unemployment rates where the accident rates show mirror images. For the US this is also the case until the early 1990s.

As is obvious from Table 1 there was a big range in the 1990 accident rate - defined as the ratio of the number of workplace accidents and the number of employees - across the OECD, from as low as 0.2% in Ireland to 5.5% in Spain and 6.5% in Portugal. These differences partly have to do with the definition of workplace accidents. In Ireland, Italy and Germany for example workplace accidents refer to incapacity of the worker due to an accident of 4 workdays or more. In Finland and the UK the threshold is 3 workdays while for most of the countries all cases of injury with lost workdays are counted as workplace accidents. Also for fatal workplace accidents there is a wide difference between countries from a low 0.001% in the Netherlands and the UK to a high 0.07% in Italy. In the same year the unemployment rate varied from 1.8% in Sweden and Switzerland to 16% in Spain. Since the differences in level of workplace accidents may have more to do with differences in data collection than they have to do with real differences it is especially the within country correlation between accident rates and unemployment rates which is interesting to investigate.

Table 2 shows for 1990 the accident rate distinguished by industry. Both within the same country as across countries there are big differences across industries. The non-fatal accident rates in manufacturing industries ranges from a low 0.8% in Ireland to a high 12.7% in Portugal. The fatal accident rate in manufacturing is with 0.001% the lowest in the Netherlands and the UK and the highest in Spain, with 0.011%. In most of the countries the accident



rates in construction are higher than those in manufacturing. The non-fatal accident rate in construction was with 0.2% the lowest in Ireland and with 16.9% the highest in Switzerland. The fatal accident rate in construction was with 0.003% the lowest in the Netherlands and with 0.028% the highest in Spain. Table 2 also shows that in trade and other industries the workplace accident rates were usually lower than those in manufacturing and construction.

## 4.2 Parameter estimates

Our empirical analysis is based on the relationship between workplace accidents and unemployment rates, which we derived in the theoretical section. As discussed before, countries differ in the way they register and collect data on workplace accidents. The structure of the workforce may influence the level of the workplace accident rate. In 1998 workers in the EU employed for less than two years were 1.2 to 1.3 times more likely to have an accident than the average worker, irrespective of whether they had a temporary or permanent contract.<sup>8</sup> Furthermore, the risk of an accident for people aged between 18 and 24 was 1.4 times the average. Also, as shown in Table 2 there are big differences between industries. This means that the industrial structure of a country will affect its workplace accident rates. In the analysis we account for these fixed differences between countries in workplace accident rate. It may also be the case that calendar year effects that account for joint influences over time are relevant. And, it may be that there are country-specific time trends that influence the evolution of workplace accidents. These country-specific time trends could reflect working conditions that gradually improve or deteriorate, changes in the industrial structure et cetera. Therefore, we add fixed effects for countries and calendar years and also country specific time trends to the relationship between non-fatal accidents and unemployment:

$$\ln(a_{i,t}) = \beta_{0i} + \beta_{0t} + \beta_{1i}\tau + \beta_2 \ln(u_{i,t}) + \varepsilon_{i,t} \quad (4)$$

where  $a$  is the non-fatal workplace accident rate,  $\tau$  is a time trend,  $u$  is the unemployment rate,  $i$  is a subscript for country,  $t$  is the subscript for time and  $\varepsilon_{i,t}$  are the error terms. When estimating the parameters of this equation we also added some country-specific dummies to account for breaks in series (see Table A1 for details). To account for possible heteroscedasticity we calculated robust standard errors. We also did similar regressions with the fatal accident

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<sup>8</sup>Based on Eurostat information on workplace accidents. Below we discuss these data in more detail.

rates ( $\ln(fa_{i,t})$ ) as dependent variable. If it is the case that reporting behavior drives the relationship between the unemployment rate and the non-fatal workplace accident rate we expect  $\beta_2$  to be significantly smaller than zero in the case of non-fatal workplace accident rates, while in the case of fatal workplace accident rates  $\beta_2$  should not differ significantly from zero.

We base our estimates on a dataset from 16 countries containing 314 observations in total. The estimation results are shown in Table 3. The first line of the table shows the parameter estimates of  $\beta_2$  for both non-fatal and fatal workplace accident rates. The elasticity of non-fatal workplace accidents with respect to unemployment equals  $-0.32$  and is significantly different from zero. It is obvious that the unemployment rate has a significant negative effect on non-fatal accidents. For fatal accidents we find an elasticity with respect to unemployment of  $-0.03$ , insignificantly different from zero. So, the first line of Table 3 indicates that the cyclical fluctuations in workplace accidents most likely have to do with cyclical fluctuations in reporting behavior. If workplace conditions would explain the cyclical behavior of non-fatal accidents, it should also be the case that fatal accidents vary with unemployment. However, the fatal accidents rate is not affected by changes in the unemployment rate.

Table 3 also contains the results of additional estimates where we introduced potential additional explanatory variables. In the theoretical section we argued that the reporting rate of workplace accidents is influenced by the consequences of becoming unemployed ( $V_u$ ). We have stressed the level effect of unemployment here, but there might also have been a separate effect of the change in unemployment. To investigate whether this is the case, we introduce  $\Delta \ln(u_{i,t})$ , the change in the unemployment rate as explanatory variable ( $\Delta$  is the indicator for first differences). As shown in the second line of Table 3 if we introduce the change in unemployment rate as additional explanatory variable the parameter estimates are very much unaffected. The change in unemployment rate affects neither the non-fatal accident rates nor the fatal workplace accident rate. Thus there is no additional effect of the change in unemployment (besides the level effect) on the number of accidents reported.

As an alternative to the reporting behavior explanation of cyclical fluctuations in workplace accidents, the workplace safety explanation predicts that the change in employment is positively related to workplace accidents since an increase in employment coincides with a lot of new hirings while a decrease in employment is related to few new hirings. The newly hired workers are less experienced than incumbent workers and hence more accident prone. This raises  $\phi$

on average and should lead to more fatal and non-fatal accidents. The third line in Table 3 introduces  $\Delta \ln(e_{i,t})$ , the change in employment  $e$  as explanatory variable. We find that this additional variable has no significant effect on either the non-fatal or the fatal accident rate.

The workplace safety explanation also predicts that working hours have a positive effect on workplace accidents because working longer increases the probability of an accident (increases  $\phi$ ). The fourth estimate in Table 3 introduces  $\ln(h_{i,t})$ , where  $h$  is the hours actually work per person employed as additional explanatory variable. As shown the estimation results hardly change and the coefficient of  $\ln(h_{i,t})$  is not significant. Apparently, the number of working hours neither affects non-fatal workplace accidents nor fatal workplace accidents.

The fifth estimate presented in Table 3 introduces as additional explanatory variable  $s$ , the share of manufacturing and construction in total employment. In these industries the accident rates are above average and it may be that cyclical fluctuations in the employment shares of these industries represent fluctuations in (economy wide) average workplace safety. There is a negative but imperfect correlation between the unemployment rate and the employment share of manufacturing and construction. So, if the unemployment rate indeed mainly affects the reporting behavior of the worker while the employment share of manufacturing and construction affects average workplace safety we expect this share to affect fatal accidents as well as non-fatal accidents. Indeed, if employment share of manufacturing and construction is the only explanatory variable there is a significant positive effect on the non-fatal accident rate. However, as shown, if the unemployment rate is also included the employment share of manufacturing and construction does not affect the non-fatal accident rate. For fatal accident rates there is a positive and significant effect. If the employment share of manufacturing and construction increases there are more fatal accidents. From this we conclude that the fatal accident rate is a suitable indicator for (economy wide) average workplace safety while for non-fatal accidents fluctuations in reporting behavior dominate fluctuations in average workplace safety.

All in all, it seems that high unemployment rates have a significant negative effect on workplace accident rates whereas changes in unemployment, changes in employment, working hours and industrial structure do not affect non-fatal accident rates. Fatal accident rates are not influenced by labor market conditions at all. From this we conclude that cyclical fluctuations in the non-fatal workplace accident rate are driven by the reporting behavior of the workers and not by changes in workplace safety.

Table 4 shows additional estimation results for the non-fatal workplace accident rates. As indicated in the theoretical section, the probability that an accident is reported equals  $\phi(1 - F(\bar{\alpha}))$ , where  $\phi$  is the exogenous probability of experiencing a workplace accident,  $\alpha$  is the disutility of the damage caused by the accidents and accidents for which  $\alpha \geq \bar{\alpha}$  are reported. The cyclical variation in the reported workplace accidents is driven by the cyclical variation in  $\bar{\alpha}$ . In the estimates in Table 4 the fatal workplace accident rate is introduced as explanatory variable, because this is a proxy for fluctuations in  $\phi$ . The first line of Table 4 shows that indeed there is a positive relationship between fatal and non-fatal workplace accidents with an elasticity of 0.20. This is our preferred estimate. We interpret this positive relation as induced by in-country variation in workplace safety. The other estimation results in Table 4 illustrate how robust the parameter estimates are by estimating our preferred regression using various subsamples.

In the second estimate of Table 4 we split the sample in two subperiods, 1976-1989 and 1990-2001. As shown for both periods we find that the unemployment rate has a negative effect on the non-fatal workplace accident rate, while the fatal accident rate has a positive effect. The third estimate shows the parameter estimates if we only include EU countries. Then, the parameter estimates are almost identical to those obtained by using the full sample.

The fourth set of estimates of Table 4 shows the parameter estimates if industry specific data on workplace accidents are used. We make a distinction between three groups of industries: manufacturing, construction and other industries. In all cases we find that the (national) unemployment rate has a significant negative effect on the industry workplace accident rates. When we distinguish between industries we no longer find that the fatal accident rates have a significant positive effect on the non-fatal workplace accident rates. We think that this may have to do with difficulties in allocating accident information to the various industries. Also, for many countries there has been a change in the industrial classification which may affect the results. Because the information at the industry level is not available for all the years used in the previous estimates the number of observations is reduced from 314 to 238.<sup>9</sup> The last line of the fourth estimates shows that for the reduced dataset we find very similar results as for the complete dataset.

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<sup>9</sup> Greece is absent completely due to the lack of separate information for fatal and non-fatal workplace accidents by industry.

In the final set of estimates in Table 4, we investigate to what extent institutions matter.<sup>10</sup> First, we make a distinction between countries with a high union density and countries with a low union density. We find that there is hardly any difference in parameter estimates for the two groups of countries. Then, we make a distinction between countries with low unemployment benefits and countries with high unemployment benefits. Now, we do find a difference. As predicted in Lemma 1, for countries with low unemployment benefits the cyclical in workplace accidents is stronger than for countries with high unemployment benefits. This confirms the reporting behavior explanation since there is no effect of unemployment benefits on workplace conditions. In countries where the consequences of unemployment, i.e. countries with high unemployment benefits, are less severe the elasticity of non-fatal workplace accidents with respect to the unemployment rate is not that big.

When we interact the level of unemployment benefits and the type of data (reported/compensated) with the unemployment rate we also find significant coefficients for the interaction terms. The estimated coefficients (t-statistics) are:

$\ln(u_{i,t})$	-0.26(6.9)
$\ln(u_{i,t}) \cdot (ub_i - \bar{ub}_i)$	0.011(5.5)
$\ln(u_{i,t}) \cdot d_{reported}$	-0.11 (2.9)
$\ln(fa_{it})$	0.19(5.3)

where  $ub$  represents unemployment benefits (replacement rates),  $d_{reported}$  is a dummy with a value of 1 if the country collects reported accidents data and a value of 0 otherwise, and all estimates contain fixed effects for country and calendar year and also include country-specific time trends. These results show that as expected in countries with low unemployment benefits and countries that have reported accident data the effect of unemployment on non-fatal workplace accidents is stronger than in other countries.

As a final sensitivity analysis we also used data from Eurostat. Eurostat publishes harmonized data on accidents at work, which are collected in the framework of the European Statistics on Accidents at Work (ESAW). The data refer to accidents at work resulting in more than 3 days absence from work (serious accidents) and fatal accidents. A fatal accident is defined as an accident which leads to the death of a victim within one year of the accident. The national

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<sup>10</sup> The information about the institutions is derived from Boone and Van Ours (2004).

ESAW sources are the declarations of accidents at work, either to the public (Social Security) or private specific insurance for accidents at work, or to other relevant national authority (Labor Inspection, etc.) for countries having a “universal” Social Security system. The Eurostat accidents at work data collection started in 1994 so that now data are available over the period 1994-2002 for 10 countries.<sup>11</sup> The main disadvantage of the Eurostat data is the short time period; the main advantage is that the data are harmonized. Table 5 gives an overview of the differences between the accident rates based on ILO information and on Eurostat information.<sup>12</sup> As shown, there are differences between the two data sources but the overall pattern is very similar: Spain has the highest accidents rate, Sweden and the UK have the lowest.

Table 6 shows parameter estimates based on the Eurostat data. Unemployment has a clear negative effect on the non-fatal accident rate. The estimated parameter is very similar to the ones presented in Tables 3 and 4. The fatal accident rate has a positive effect on the non-fatal accidents rate. The number of annual working hours also has a positive effect on the non-fatal accident rate, which seems to make more sense than the negative (although insignificant) effect found in table 3. The intuition here is that the more hours an employee works per year, the more likely he is to experience a work related accident (even if the accident rate per hour is unchanged).<sup>13</sup>

## 5 Conclusions

In recessions the rate of workplace accidents is lower than it is in booms. We distinguish between two possible explanations for this phenomenon: workplace safety and reporting behavior. The workplace safety explanation predicts that the unemployment rate is negatively related to workplace accidents because effort is negatively related to unemployment and high effort makes accidents more likely. Furthermore, it predicts that working hours are positively related to workplace accidents because working longer increases the probability of an accident to occur.

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<sup>11</sup>Data are available for more than 10 countries but over a shorter time period. There is also information about severity of accidents but not on a time series cross country basis.

<sup>12</sup>The rate are calculated using the same information about employment (see Appendix 1) so that the only difference between the two series refers to the nominators.

<sup>13</sup>Although not reported, unemployment has again an insignificant effect on the fatal accidents rate, which is in line with estimates presented in Table 3.

Also, the change in employment is positively related to workplace accidents since an increase in employment coincides with a lot of new hirings while a decrease in employment is related to few new hirings. The ‘reporting’ explanation predicts that the rate of unemployment is negatively related to the rate of workplace accidents. Workers fear that the chance that they are fired goes up next time the firm needs to shed labor if they report an accident. If unemployment is high, it will take a long time before another job is found and hence the worker prefers not to report an accident. Another distinction between the two alternative explanations has to do with fatal accidents. If cycles in workplace safety drive the cycles in workplace accidents this should also be the case for fatal accidents. If reporting behavior of workers is relevant then fatal accidents should not be affected by the unemployment rate or changes in the unemployment rate, because fatal accidents are always reported.

In our empirical analysis based on information from OECD countries we find that workplace accidents are inversely related to the unemployment rate, while working hours and changes in employment rate do not affect the accident rate. Furthermore, fatal accident rates do not seem to be related to labor market conditions in terms of unemployment. When we include the fatal workplace accident rate as explanatory variable we find a positive and significant effect on non-fatal accidents. Fatal accidents turn out to be related to the employment shares of manufacturing and construction. Thus fatal workplace accidents are an indicator of economy wide workplace safety. Therefore, our results imply that the variation in non-fatal workplace accidents is related to both economy wide workplace safety (through employment shares of industries) and reporting behavior (as picked up by the unemployment rate). In our sensitivity analysis we also find that these results are robust for various subsamples related to different time periods and different groups of countries. When we interact the level of unemployment benefits with the unemployment rate we find a positive coefficient for the interaction term. So, the higher the unemployment benefits the smaller the effect of unemployment on non-fatal workplace accidents. This is again an indication of the relevance of reporting behavior.

From all this we conclude that labor market conditions influence statistical information on workplace accidents through reporting behavior of workers. If unemployment is high workers are less likely to report about workplace accidents than they are in situations of low unemployment. We find no evidence that workplace safety deteriorates in cyclical upturns or that recessions are good for workplace safety.

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## 6 Appendix 1: Information about the data

The thirteenth International Conference of Labor Statisticians (Geneva, 1992) defined work accidents as accidents occurring at or in the course of work which may result in death, personal injury or disease. International comparisons of information about workplace accidents are difficult because sources of data, reporting procedures and coverage of the data may differ between countries. Coverage may be limited to certain types of workers or injuries giving rise to more than a certain number of days of absence from work.

The sources of information for the data used in the analysis are the following:

- Workplace accidents: ILO Bureau of statistics (LABORSTA)
- Unemployment rates: OECD labor force statistics
- Employment and working hours: GGDC: University of Groningen and The Conference Board, Growth & Development Center Total Economy Database, 2002, <http://www.eco.rug.nl/ggdc>

Although for some countries information about workplace accidents goes back to 1970 for most of the countries considered this information starts in later years. Therefore, our (maximum) calendar period is 1975-2001. Table A1 describes some general characteristics of the information on workplace accidents.

**Table A1 Information about workplace accidents in ILO statistics**

	Source <sup>a)</sup>	Subject <sup>b)</sup>	Minimum period (days)	Period	Breaks <sup>c)</sup>
<b>Belgium<sup>d)</sup></b>	FA	82	1	1984-2001	s93-97,s98-01
<b>Canada</b>	FA	82	1	1985-2000	
<b>Denmark</b>	FF	81	1	1978-2001	s91-01
<b>Finland</b>	FA	82	3	1978-2000	s93-00
<b>France</b>	FA	82	1	1975-2000	
<b>Germany<sup>e)</sup></b>	FA	82	4	1990-2000	
<b>Greece</b>	FA	82	1	1979-1999	s82-99
<b>Ireland</b>	FF	81	4	1976-1999	s90-99
<b>Italy</b>	FA	82	4	1979-2001	s91-01
<b>Netherlands</b>	FA	81	1	1976-1989	
<b>Portugal</b>	FA	81	1	1979-2000	s89-00
<b>Spain<sup>e)</sup></b>	FA	81	1	1980-2001	s88-01
<b>Sweden</b>	FA	81	1	1979-2000	d94
<b>Switzerland</b>	FA	82	1	1984-2000	
<b>United Kingdom</b>	FF	81	3	1986-2000	d98
<b>United States</b>	DA	81	1	1976-1991	

<sup>a)</sup> ILO classification. Source: DA = labor related establishment survey, FA = insurance records, FF = labor inspectorate records.

<sup>b)</sup> Subject: 81 = reported, 82 = compensated

<sup>c)</sup> Breaks in series as accounted for in the empirical analysis; s = shift concerning a time period; d = dummy variable for a particular year

<sup>d)</sup> Including commuting accidents

<sup>e)</sup> Fatal accidents: deaths occurring within one month of accident

## 7 Appendix 2: Mathematical results

**Proposition 1** Consider a time path for the value of being unemployed  $V_u(t)$  and an alternative time path  $V_u(t) + \varepsilon$ . Then  $\varepsilon > 0$  implies that the number of accidents reported under the alternative time path exceeds the number of accidents reported under the original time path.

**Proof of proposition** We begin with some preliminary results that will be used later on. In particular, we introduce a class of differential equations which we do not solve as initial value problems. Instead we impose a condition on the steady state behavior of the solution to the differential equation.

**Lemma 1** Let  $g(\cdot)$  be a real valued function of  $t \in \mathbb{R}$  with  $|g(\cdot)| < M$  for some  $M > 0$ . Consider the differential equation

$$\psi h(t) = g(t) + \dot{h}(t) \quad (5)$$

with the following boundary condition: if for some  $T > 0$  it is the case that  $g(t) = \bar{g}$  for all  $t \geq T$  then  $h(t) = \frac{\bar{g}}{\psi}$  for all  $t \geq T$ .

The solution to this differential equation is

$$h(t) = \frac{1}{\psi} \bar{g}^\psi(t)$$

where

$$\bar{g}^\psi(t) \equiv \psi \int_t^{+\infty} e^{-\psi(s-t)} g(s) ds$$

### Proof

To solve differential equation (5) we solve the homogenous part of the equation first, that is

$$\psi h(t) = \dot{h}(t)$$

The solution to this equation is clearly

$$h(t) = ce^{\psi t}$$

In order to solve the original equation, we write the constant  $c$  as a function of  $t$ . So we try as a solution  $h(t) = c(t)e^{\psi t}$ . Substituting this into equation (5), we get

$$\psi c(t)e^{\psi t} = g(t) + c'(t)e^{\psi t} + \psi c(t)e^{\psi t}$$

or equivalently

$$c'(t) = -e^{-\psi t} g(t)$$

So we can solve  $c(t)$  as

$$c(t) = \int_t^{+\infty} e^{-\psi s} g(s) ds + c_0$$

for some constant  $c_0$ . Substituting this into  $h(t) = c(t) e^{\psi t}$  we get

$$h(t) = \left( \int_t^{+\infty} e^{-\psi s} g(s) ds + c_0 \right) e^{\psi t}$$

Using the boundary condition that  $g(t) = \bar{g}$  for all  $t$  must imply  $h(t) = \frac{\bar{g}}{\psi}$  yields  $c_0 = 0$ . Hence we find as solution to equation (5)

$$\begin{aligned} h(t) &= \int_t^{+\infty} e^{-\psi(s-t)} g(s) ds \\ &= \frac{1}{\psi} \bar{g}^\psi(t) \end{aligned}$$

Q.E.D.

**Lemma 2** Let  $\bar{g}^\delta(t)$  denote

$$\bar{g}^\delta(t) \equiv \delta \int_t^{+\infty} e^{-\delta(s-t)} g(s) ds$$

for  $\delta > 0$  then

$$\overline{\bar{g}^\delta}^\psi(t) \equiv \psi \int_t^{+\infty} e^{-\psi(s-t)} \bar{g}^\delta(s) ds = \frac{\bar{g}^\delta(t) - \frac{\delta}{\psi} \bar{g}^\psi(t)}{1 - \frac{\delta}{\psi}} \quad (6)$$

for  $\psi > 0$ .

### Proof

Using integration by parts we get

$$\begin{aligned} \overline{\bar{g}^\delta}^\psi(t) &= \delta \left\{ \begin{aligned} & \left[ -e^{-\psi(s-t)} \int_s^{+\infty} e^{-\delta(\tau-s)} g(\tau) d\tau \right]_t^{+\infty} + \\ & + \int_t^{+\infty} e^{-\psi(s-t)} \left[ -g(s) + \delta \int_s^{+\infty} e^{-\delta(\tau-s)} g(\tau) d\tau \right] ds \end{aligned} \right\} \\ &= [\bar{g}^\delta(t)] - \delta \int_t^{+\infty} e^{-\psi(s-t)} g(s) ds + \delta \int_t^{+\infty} e^{-\psi(s-t)} \delta \int_s^{+\infty} e^{-\delta(\tau-s)} g(\tau) d\tau ds \\ &= \bar{g}^\delta(t) - \frac{\delta}{\psi} \bar{g}^\psi(t) + \frac{\delta}{\psi} \overline{\bar{g}^\delta}^\psi(t) \end{aligned}$$

and hence the result in equation (6) follows. Q.E.D.

**Lemma 3** *The solution to differential equations (1) and (2), where  $V_u(t)$  is some function of time  $t$  satisfying the conditions in the text, can be characterized as follows*

$$V_A(t) = \frac{w + \phi \int_0^{+\infty} [-\alpha + \gamma(\alpha)] f(\alpha) d\alpha}{\rho + \delta_A} + \frac{\delta_A}{\rho + \delta_A} \bar{V}_u^{\rho + \delta_A}(t) \quad (7)$$

$$\begin{aligned} V_E(t) - V_A(t) &= \frac{-\phi \int_0^{\bar{\alpha}} \gamma(\alpha) f(\alpha) d\alpha + (\delta_A - \delta_E) \frac{w + \phi \int_0^{+\infty} [-\alpha + \gamma(\alpha)] f(\alpha) d\alpha}{\rho + \delta_A}}{\rho + \delta_E + \phi(1 - F(\bar{\alpha}))} + \\ &(\delta_A - \delta_E) \frac{\bar{g}^{\rho + \delta_E + \phi(1 - F(\bar{\alpha}))}(t)}{\rho + \delta_E + \phi(1 - F(\bar{\alpha}))} \end{aligned} \quad (8)$$

where  $\bar{\alpha}$  is determined by  $\gamma(\bar{\alpha}) = V_E(t) - V_A(t)$  and the function  $g(\cdot)$  is defined as

$$g(t) \equiv \frac{\delta_A}{\rho + \delta_A} \bar{V}_u^{\rho + \delta_A}(t) - V_u(t) \quad (9)$$

### Proof

Consider first the equation for  $V_A(t)$ . Writing equation (2) as

$$(\rho + \delta_A) V_A(t) = w + \phi \int_0^{+\infty} [-\alpha + \gamma(\alpha)] f(\alpha) d\alpha + \delta_A V_u(t) + \dot{V}_A(t) \quad (10)$$

we see it is a differential equation of the form (5). Hence lemma 1 implies that the solution can be written as equation (7).

Now turn to the difference  $V_E(t) - V_A(t)$ . Writing equation (1) as

$$\begin{aligned} (\rho + \delta_E) V_E(t) &= w - \phi \int_0^{+\infty} \alpha f(\alpha) d\alpha + \phi \int_{\bar{\alpha}}^{+\infty} [\gamma(\alpha) - (V_E(t) - V_A(t))] f(\alpha) d\alpha + \\ &\delta_E V_u(t) + \dot{V}_E(t) \end{aligned} \quad (11)$$

where  $\bar{\alpha}$  is the smallest value of  $\alpha$  for which

$$\max \{ \gamma(\alpha) - (V_E(t) - V_A(t)), 0 \} = \gamma(\alpha) - (V_E(t) - V_A(t))$$

(recall that  $\gamma(\cdot)$  is nondecreasing in  $\alpha$ ). In other words, by continuity of  $\gamma(\cdot)$ , we have that

$$\gamma(\bar{\alpha}) = V_E(t) - V_A(t)$$

Subtracting from (11) equation (10), we get

$$\begin{aligned} &(\rho + \delta_E) [V_E(t) - V_A(t)] + (\delta_E - \delta_A) V_A(t) \\ &= -\phi \int_0^{\bar{\alpha}} \gamma(\alpha) f(\alpha) d\alpha - \phi [V_E(t) - V_A(t)] (1 - F(\bar{\alpha})) \\ &\quad - (\delta_A - \delta_E) V_u(t) + [\dot{V}_E(t) - \dot{V}_A(t)] \end{aligned}$$

Defining  $\Delta_{EA}(t) \equiv V_E(t) - V_A(t)$  and substituting into this equation the solution for  $V_A(t)$  in equation (7) we find

$$\begin{aligned} (\rho + \delta_E + \phi(1 - F(\bar{\alpha}))) \Delta_{EA}(t) &= -\phi \int_0^{\bar{\alpha}} \gamma(\alpha) f(\alpha) d\alpha + \\ &(\delta_A - \delta_E) \frac{w + \phi \int_0^{+\infty} [-\alpha + \gamma(\alpha)] f(\alpha) d\alpha}{\rho + \delta_A} + \\ &(\delta_A - \delta_E) \left( \frac{\delta_A}{\rho + \delta_A} \bar{V}^{\rho + \delta_A}(t) - V_u(t) \right) + \dot{\Delta}_{EA}(t) \end{aligned}$$

First, note that  $\bar{\alpha}$  is a function of  $\Delta_{EA}(t)$ , but due to an Envelope Theorem type of argument we can ignore this indirect effect on  $V_E$  via  $\bar{\alpha}$ . Therefore we can also ignore the effect of a change in  $\bar{\alpha}$  on  $\Delta_{EA}(t)$ . Second, note that this differential equation for  $\Delta_{EA}(t)$  has the same form as equation (5). Applying the solution in lemma 1 gives us equation (8) above. Q.E.D.

Now we can characterize the proof of the proposition above.

The number of accidents reported at time  $t$  depends negatively on  $\Delta_{EA}(t)$  because  $\gamma(\bar{\alpha}) = \Delta_{EA}$  and the fraction of accidents reported equals  $(1 - F(\bar{\alpha}))$ . Hence showing that under time path  $V_u(t) + \varepsilon$  with  $\varepsilon > 0$  more accidents are reported than under time path  $V_u(t)$  boils down to showing that  $\Delta_{EA}(t)$  is lower with  $V_u(t) + \varepsilon$  than with  $V_u(t)$ . Looking at the solution in equation (8), a sufficient condition for this is that  $g(t)$  as defined in equation (9) is always lower under path  $V_u(t) + \varepsilon$  than under path  $V_u(t)$ . Let  $g_\varepsilon(t)$  denote the path for  $g(t)$  under  $V_u(t) + \varepsilon$  while  $g_0(t)$  denotes the path under  $V_u(t)$ . Then we want to prove that  $g_0(t) - g_\varepsilon(t)$  is positive for all  $t$ . It is routine to verify that

$$\begin{aligned} g_0(t) - g_\varepsilon(t) &= \left[ \frac{\delta_A}{\rho + \delta_A} \bar{V}_u^{\rho + \delta_A}(t) - V_u(t) \right] \\ &\quad - \left[ \frac{\delta_A}{\rho + \delta_A} (\bar{V}_u^{\rho + \delta_A}(t) + \varepsilon) - (V_u(t) + \varepsilon) \right] \\ &= \varepsilon \frac{\rho}{\rho + \delta_A} > 0 \end{aligned}$$

*Q.E.D.*

### **Proof of lemma 1**

To find the effect of a change in  $u$  on the value of being unemployed  $V_u$ , we define  $\Delta_{Eu}$  as follows:

$$\Delta_{Eu} = V_E - V_u$$



In general  $\Delta_{Eu}$  will be a function of  $V_u$ :  $\Delta_{Eu}(V_u)$ . The higher  $V_u$  is the smaller this difference becomes,  $\Delta'_{Eu}(V_u) < 0$ . Differentiating the expression for the value of being unemployed with respect to  $u$  we get

$$(\rho + q(u)(-\Delta'_{Eu}(V_u))) \frac{dV_u}{du} = q'(u) \Delta_{Eu}$$

or equivalently

$$\frac{dV_u}{du} = \frac{q'(u) \Delta_{Eu}(V_u)}{(\rho + q(u)(-\Delta'_{Eu}(V_u)))} < 0$$

because  $q'(u) < 0$ . Hence we find

$$\frac{d\left(\frac{dV_u}{du}\right)}{db} = q'(u) \frac{\Delta'_{Eu}(V_u)(\rho + q(u)(-\Delta'_{Eu}(V_u))) - \Delta_{Eu}(V_u)q(u)(-\Delta''_{Eu}(V_u)) \frac{dV_u}{db}}{(\rho + q(u)(-\Delta'_{Eu}(V_u)))^2} > 0$$

*Q.E.D.*

## 8 Tables and graphs

Table 1 Fatal accidents, non-fatal accidents and unemployment rates; 1990<sup>a)</sup>

	Fatal accidents		Non-fatal accidents		Unemployment rate
	(#)	(0.01%)	(1000)	(%)	(%)
Belgium	106	0.3	115	3.2	7.2
Canada	943	0.6	594	4.7	8.1
Denmark	71	0.3	46	1.7	8.3
Finland	74	0.3	103	4.1	3.1
France	1213	0.6	760	3.9	9.2
Germany	1712	0.5	1902	5.3	8.4
Greece	84	0.2	28	0.7	7.0
Ireland	73	0.6	3	0.2	14.8
Italy	1423	0.7	922	4.3	11.4
Netherlands	59	0.1	66	1.1	8.2
Portugal	203	0.4	305	6.5	4.7
Spain	1446	1.1	695	5.5	16.0
Sweden	117	0.3	87	2.0	1.8
Switzerland	153	0.4	142	3.8	1.8
United Kingdom	359	0.1	184	0.7	6.8
United States	2900	0.2	3124	2.6	5.6
<b>Total</b>	10,936	-	9076	-	-

<sup>a)</sup> Number of accidents as a percentage of the number of workers; unemployment as % of the labor force; Germany 1994; Ireland and Switzerland 1991; Netherlands 1989.

Table 2 Fatal accident rate and non-fatal accident rates by industry; 1990<sup>a)</sup>

Industry	Fatal accidents (0.01%)					Non-fatal accidents (%)				
	3	5	6	10	Total	3	5	6	10	Total
Belgium	0.4	0.6	0.3	0.2	<b>0.3</b>	6.4	8.0	2.9	1.2	<b>3.2</b>
Canada	0.6	2.0	0.2	0.7	<b>0.6</b>	9.6	7.9	4.2	3.1	<b>4.7</b>
Denmark	0.3	0.6	0.1	0.2	<b>0.3</b>	3.4	2.5	0.6	1.2	<b>1.7</b>
Finland	0.3	0.9	0.1	0.2	<b>0.3</b>	7.8	10.9	2.8	2.1	<b>4.1</b>
France	0.7	2.7	0.6	0.3	<b>0.6</b>	7.1	12.6	3.9	1.7	<b>3.9</b>
Germany	0.3	1.2	0.2	0.5	<b>0.5</b>	5.0	12.3	3.5	4.7	<b>5.3</b>
Greece	-	-	-	-	-	1.9	2.3	0.3	0.3	<b>0.7</b>
Ireland	0.2	1.3	-	0.9	<b>0.6</b>	0.8	0.2	0.1	0.1	<b>0.2</b>
Italy	0.6	1.8	0.1	0.7	<b>0.7</b>	7.4	7.6	1.3	3.6	<b>4.3</b>
Netherlands	0.1	0.3	0.1	0.1	<b>0.1</b>	1.9	3.8	1.0	0.5	<b>1.1</b>
Portugal	0.4	1.3	0.2	0.4	<b>0.4</b>	12.7	15.3	4.1	2.8	<b>6.5</b>
Spain	1.1	2.8	0.6	1.0	<b>1.1</b>	10.3	11.4	4.1	2.7	<b>5.5</b>
Sweden	0.2	0.7	0.1	0.3	<b>0.3</b>	3.4	4.0	1.2	1.4	<b>2.0</b>
Switzerland	0.5	2.2	0.1	0.3	<b>0.4</b>	5.4	16.9	2.4	1.9	<b>3.8</b>
United Kingdom	0.1	0.5	0.0	0.1	<b>0.1</b>	1.1	0.9	0.3	0.6	<b>0.7</b>
United States	0.2	0.9	0.2	0.2	<b>0.2</b>	5.0	3.9	2.9	1.6	<b>2.6</b>

<sup>a)</sup> Number of accidents as a percentage of the number of workers; ISIC classification 2: 3 = Manufacturing, 5 = Construction, 6 = Trade, 10 = All other industries; Germany 1994; Greece: non-fatal accident rate include fatal accidents; Ireland and Switzerland 1991; Netherlands 1989.

**Table 3 Estimation results non-fatal and fatal accident rates<sup>a)</sup>**

	Non-fatal accidents		Fatal accidents		N	d.f.
	coeff. (t-stat.)	$\bar{R}^2$	coeff. (t-stat.)	$\bar{R}^2$		
(1) $\ln(u)$	-0.32 (9.2)	0.988	-0.03 (0.5)	0.956	314	245
(2) $\ln(u)$	-0.31 (8.4)		-0.03 (0.5)			
$\Delta \ln(u)$	-0.04 (0.7)	0.988	0.03 (0.3)	0.855	314	245
(3) $\ln(u)$	-0.31 (9.1)		-0.02 (0.3)			
$\Delta \ln(e)$	0.35 (0.9)	0.988	0.37 (0.8)	0.955	314	245
(4) $\ln(u)$	-0.31 (9.1)		-0.04 (0.6)			
$\ln(h)$	-0.23 (0.4)	0.987	-1.07 (1.4)	0.957	298	232
(5) $\ln(u)$	-0.30 (7.4)		0.08 (1.2)			
$s$	0.88 (0.6)	0.990	5.44 (2.6)	0.960	276	204

<sup>a)</sup> All estimates contain country fixed effects, calendar year fixed effects, country-specific time trends and dummy variables for structural breaks (see Table A1 for an overview);  $u$  = unemployment rate,  $e$  = employment,  $h$  = average annual number of hours of work,  $s$  = employment share of manufacturing and construction; absolute t-values in parentheses;  $\bar{R}^2$  is corrected for degrees of freedom (d.f.).

**Table 4 Estimation results non-fatal accident rates<sup>a)</sup>**

		$\ln(u)$	$\ln(fa)$	$\bar{R}^2$	$N$	d.f.
<b>(1)</b>	All	-0.31 (9.5)	0.20 (4.2)	0.989	314	244
<b>(2)</b>	1976-1989	-0.19 (2.5)	0.17 (2.9)	0.990	157	108
	1990-2001	-0.27 (4.6)	0.11 (1.7)	0.991	157	109
<b>(3)</b>	EU only	-0.32 (9.2)	0.20 (4.1)	0.989	265	201
<b>(4)</b>	<b>Industry-specific</b>					
	Manufacturing	-0.27 (7.6)	0.01 (0.2)	0.986	238	170
	Construction	-0.46 (5.3)	-0.05 (0.2)	0.891	238	170
	Other industries	-0.41 (4.2)	0.17 (0.5)	0.981	238	170
	All	-0.33 (9.3)	0.12 (2.4)	0.990	238	170
<b>(5)</b>	<b>Institutions</b>					
	<i>Union density</i>					
	High	-0.25 (6.2)	0.12 (1.3)	0.970	111	87
	Low	-0.21 (7.0)	0.24 (4.7)	0.992	203	147
	<i>Unemployment benefits</i>					
	High	-0.15 (3.6)	0.20 (2.8)	0.957	148	120
	Low	-0.31 (9.5)	0.13 (1.8)	0.989	166	134

<sup>a)</sup> See footnote *a* Table 3 and the main text for explanatory information.

Table 5 Comparing accident information of ILO and Eurostat; 2000<sup>a)</sup>

	Non fatal accidents (%)		Fatal accidents (0.01%)	
	ILO	Eurostat	ILO	Eurostat
<b>Austria</b>	-	2.7	-	0.63
<b>Belgium</b>	2.6	2.5	0.19	0.29
<b>Denmark</b>	1.8	2.7	0.25	0.25
<b>France</b>	3.1	3.1	0.31	0.36
<b>Germany</b>	4.1	3.9	0.32	0.28
<b>Greece</b>	0.4	1.0	0.30	0.26
<b>Italy</b>	2.8	3.1	0.50	0.52
<b>Spain</b>	6.1	4.9	0.74	0.53
<b>Sweden</b>	0.9	1.2	0.14	0.14
<b>United Kingdom</b>	0.6	1.4	0.07	0.10

<sup>a)</sup> Greece 1999; Eurostat UK = Great Britain.

**Table 6 Estimation results non-fatal accident rates - Eurostat data; 1994-2002<sup>a)</sup>**

	$\ln(\mathbf{u})$	$\ln(\mathbf{fa})$	$\ln(\mathbf{h})$	$\bar{R}^2$	d.f.
<b>1.</b>	-0.34 (2.9)	0.11 (2.0)	1.25 (1.8)	0.985	60
<b>2.</b>	-0.32 (2.7)	0.10 (1.8)	-	0.985	61
<b>3.</b>	-0.35 (2.9)	-	-	0.984	60

<sup>a)</sup> The estimates are based on information from 10 countries (90 observations; see main text); See also footnote *a* Table 3 for explanatory information.

**Figure 1 Evolution of rates of non-fatal workplace accidents and unemployment;  
16 countries**

*see next pages*







