Cyclical fluctuations in workplace accidents

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Abstract

This paper presents a theory and an empirical investigation on cyclical fluctuations in workplace accidents. 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. Therefore a country with a high or an increasing unemployment rate has a low (reported) workplace accident rate. The empirical investigation concerns workplace accidents in OECD countries. The analysis confirms that workplace accident rates are inversely related to both the level of unemployment and the change in unemployment. Furthermore, fatal accident rates do not fluctuate over the cycle. We conclude that our empirical analysis is in line with our theory: cyclical fluctuations in workplace accidents have to do with reporting behavior of workers and not with changes in workplace safety.

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1 Introduction

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."[1] Workplace accidents are a common phenomenon. In the EU during 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 accidents, 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. Around 150 million working days are lost, which is about 0.5% of total working time.[2]

The rate of workplace accidents differs between countries and changes over time. Cross-country differences in workplace accident rates are mainly related to differences in definitions and measurement. The changes over time are more difficult to explain. Some countries have a downward trend in their accident rates because of safer work conditions or changes in industrial structure. However a decline in accident rate is not present in every country. Furthermore, as we will show in more detail below, workplace accident rates are procyclical, which could indicate that on average work is more dangerous in booms than it is in slumps. If so, this would be in line with evidence presented by Ruhm (2000) indicating that

[1] 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.

[2] Information from the European Agency for Safety and Health at Work - Facts 19.

booms are unhealthy. Ruhm finds a strong inverse 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.[3] This explanation for the procyclicality of workplace accidents has to do with working conditions. In booms the effort level of workers is higher and more inexperienced workers are hired. The idea is that when employers require high effort levels from their workers, these workers become less careful. Hence the number 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 (employers require higher effort levels in booms) so are workplace accidents. Consequently, workplace accidents are negatively correlated with unemployment. 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 are more accidents in a boom.

An alternative explanation for the cyclicality in workplace accidents is related to the well-known procyclical variation in workers' absenteeism. If unemployment is high, workers fear to loose 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

[3] Ruhm (2000) investigates the relationship between economic conditions and health, using U.S. state specific data. Other possible reasons for the inverse 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.

are reluctant to report these accidents when they fear that employers will hold this against them. For an individual worker the probability to be dismissed is equal to the product of the average probability to be dismissed and the ratio of individual specific probability and average probability. The first probability depends on the economic position of the firm, which in itself will generally depend on the macroeconomic situation, i.e. the cycle. The second ratio depends on the behavior of the individual compared to the behavior of his or her colleagues and may be related to a workplace accident. Therefore, workers may be reluctant to report a workplace accident. The reporting rate of workplace accidents may be influenced by the perceived likelihood of being dismissed because of the accident and by the consequences of being unemployed conditional on a particular dismissal probability. The two determinants of the reporting rate have different implications for the cyclical behavior. The first determinant implies that the reporting rate is low if unemployment is increasing, while the second determinant implies that the reporting rate is low if unemployment is high.

This paper focuses on the question whether high workplace accidents rates in a boom are a true phenomenon related to stress or inexperienced workers and thus an indication of workers' health being harmed in prosperous times or whether alternatively high workplace accidents rates in a boom are a spurious phenomenon caused by changes in workers reporting behavior. The two explanations for the cyclicality 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 'working conditions' explanation predicts that the level of unemployment is negatively related to workplace accidents. Furthermore, it predicts that working hours have a positive effect on workplace accidents because working longer increases the probability of an accident. 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. If working conditions are the driving force not only the non-fatal accidents but also the fatal accidents will exhibit cyclicality. The 'reporting' explanation predicts that both the level and the change in unemployment are negatively related to workplace accidents. Furthermore, the cyclicality should be found only in the case of non-fatal accidents and should not be found in the case of fatal accidents because there is no reporting decision in the latter case.

In our empirical analysis it appears that both the level and the change in unemployment are negatively related to workplace accidents while working hours and the change in employment have no effect on workplace accidents. Furthermore, cyclicality is found only for non-fatal workplace accidents. From this evidence 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 upturns 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 cyclicality in reported workplace accidents showing that both the level of unemployment and the change in unemployment affect the reported workplace accidents. Section 4 describes the data on workplace accidents from 17 OECD countries, discusses the statistical model and presents estimation results. Section 5 concludes.

2 Previous studies

There are several studies that investigate the cyclicality 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 (2001) 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, Askild-

sen 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 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 unobserv-

able labor effort. This idea comes from Shea (1990) who suggests that accidents only occur in the workplace if labor really works. Therefore 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. If firms require more effort from labor in booms and less in recessions, then labor effort will be pro-cyclical and the injury rate will be 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 accident rates 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 US 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 output and workplace accidents. The idea is that reporting an accident dents 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 or decreasing. 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 an indicator of the cycle. Hence the model relates unemployment to workplace accidents in the following two ways.

First, comparing two countries where one has higher unemployment than the other, we show that, ceteris paribus, the country with the higher unemployment rate has a smaller number of reported workplace accidents. Second, following two countries over time, if unemployment increases faster in one country than in the other we show that, ceteris paribus, the number of reported workplace accidents is smaller in the country with the biggest rise in unemployment.

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 (non-fatal) 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.

Consider the following model of workplace accidents. Each worker has an exogenous probability ϕ of experiencing a (non-fatal) workplace accident. 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 $f(.)$ and distribution function $F(.)$. After the accident has happened, a worker decides whether to report it or not. If he reports the accident, the firm pays him 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 concludes 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.

Using a dynamic model of the labour 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.[4] We assume that $V_E(t)$ is determined by the following Bellman equation

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

where ρ 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 δ_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 δ_E and the change in the value of $V_E(t)$.

We assume that either the wage is determined by Nash bargaining[5] 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

[4] 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.

[5] 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.

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 $V_u(.)$. The time path for $V_A(.)$ is derived below. The time path for $V_u(.)$ can be perfectly predicted by agents[6] and we assume that $|V_u(.)| < M$ 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 α of the damage. Then the worker decides whether to report the accident or not. If 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 $V_E(t)$. Clearly, this reporting decision is only relevant for non-fatal accidents since fatal accidents are always reported.

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 δ_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 $\delta_A > \delta_E$. We also

[6] 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.

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 δ_A is nondecreasing in the number of accidents reported. Since we assume that δ_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 $V_E(t) > V_A(t)$.

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 $V_u(.)$ affects the difference $V_E(.) - V_A(.)$, because that is the channel through which the unemployment rate affects the number of accidents reported. Now we solve the differential equations (1) and (2) with an exogenous path for $V_u(.)$ not as initial value problems, but as a boundary value problem in the following sense. Suppose that for some $T > 0$ it is the case that $V_u(t) = \bar{V}_u$ for all $t \geq T$. Then we want the solutions $V_E(t)$ and $V_A(t)$ to converge to the solutions of (1) and (2) with $\dot{V}_A(t) = \dot{V}_E(t) = 0$. So, for instance, $V_A(t)$ should converge to $V_A = \frac{w + \phi \int_0^{+\infty} [-\alpha + \gamma(\alpha)] f(\alpha) d\alpha}{\rho + \delta_a} + \frac{\delta_A}{\rho + \delta_A} \bar{V}_u$. This is

the solution that follows from perfect foresight.

Before specifying how $V_u(t)$ is determined, we can derive the effect of $V_u(t)$ on the number of reported accidents. This we do in two different ways. First, we look at pure level effects. Second, we consider two different time paths for $V_u(.)$ but control for level effects so as to focus on the effect of a changing derivative $\dot{V}_u(t)$. The pure level effect can be characterized as follows. All results are proved in appendix 2.

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.*

This is a pure level effect, since for each t the two time paths for $V_u(.)$ are exactly the same (same time derivatives etc.) up to a shift in the level of V_u. The intuition for the result is that under the alternative time path (with $\varepsilon > 0$) becoming unemployed is not as bad as under the original time path. Hence reporting an accident (which makes a worker unemployed sooner, in expected terms) has not such negative consequences under the alternative time path than under the original. Hence, one would expect to see more accidents reported under the alternative time path.

In order to compare the number of accidents reported for two different time paths of $V_u(.)$ controlling for the level effect, we need to introduce some notation first. Given a real valued function $g(.)$ of time t with $|g(.)| < M$ for some $M > 0$, we define the function $\bar{g}^{\psi}(t)$ for $\psi > 0$ as

$$\bar{g}^{\psi}(t) = \psi \int_t^{+\infty} e^{-\psi(s-t)} g(s)\, ds \tag{3}$$

In words, $\bar{g}^{\psi}(t)$ is a weighted average of all future values of $g(.)$ starting from time t. Note that $\psi \int_t^{+\infty} e^{-\psi(s-t)} ds = 1$ and hence equation (3) is indeed a weighted

average.[7] We see $\bar{g}^{\psi}(t)$ as a summary of the long run behavior of the function $g(.)$ as of time t. Now we can formulate how we compare two different time paths for V_u controlling for level effects.

Proposition 2 *Consider two time paths $V_{u1}(t)$ and $V_{u2}(t)$ which satisfy*

$$\begin{aligned} V_{u1}(0) &= V_{u2}(0) \\ \bar{V}_{u1}^{\rho+\delta_A}(0) &= \bar{V}_{u2}^{\rho+\delta_A}(0) \end{aligned}$$

there exists a value of $T > 0$ such that

$$V_{u1}(t) = V_{u2}(t) \text{ for all } t \geq T$$

Then $\dot{V}_{u1}(0) > \dot{V}_{u2}(0)$ implies that the number of accidents reported at time $t = 0$ is smaller under time path V_{u2} than under V_{u1}.

The proposition considers two time paths where the first is either more steeply upward sloping than the second, or the first is upward sloping while the second is downward sloping, or the second is more steeply downward sloping than the first at $t = 0$. We are interested in the effect of this inequality $\dot{V}_{u1}(0) > \dot{V}_{u2}(0)$ on the number of reported accidents. Figure 1 illustrates a possible time path for $V_{u2}(t) - V_{u1}(t)$. The three conditions in the proposition take out the level effects. In particular, the first condition makes sure that both paths start at the same value, $V_{u1}(0) = V_{u2}(0)$. So there is no level effect to start with. The third condition makes sure that the two paths coincide from some time $T > 0$ onward, hence there are no long term level effects either.

The second condition is slightly more subtle. It is relatively straightforward to see that the first and the third condition are not sufficient to eliminate level effects.

[7] In fact, the weights follow an exponential distribution. Also, note that the definition of $\bar{g}^{\psi}$ is closely related to a Laplace transformation.

For instance, a time path $V_{u2}(t)$ with $V_{u1}(0) = V_{u2}(0)$ but which otherwise lies everywhere below $V_{u1}(t)$ for $t \in \langle 0, T\rangle$ and coincides again with $V_{u1}(.)$ for all $t \geq T$ satisfies the two conditions. Yet, there is still a level effect since the second time path is unambiguously worse for an agent than the first. To avoid this latter effect, it must be the case that the initial negative difference $V_{u2}(t) - V_{u1}(t)$ is compensated later on by a positive difference, as illustrated by Figure 1. This is exactly what the second condition, $\bar{V}_{u1}^{\rho+\delta_A}(0) = \bar{V}_{u2}^{\rho+\delta_A}(0)$, ensures. It says that the long run behavior of the two time paths, as seen from time $t = 0$, is the same. One time path does not yield a consistently higher or lower value than the other path. In particular, this condition implies that the two time paths for V_u have the same value for V_A at time $t = 0$ (for details see the appendix).

The result now says that comparing two time paths for V_u, where all level effects have been removed, and where it is the case that $\dot{V}_{u1}(0) > \dot{V}_{u2}(0)$ we find that the number of accidents reported at time $t = 0$ is higher under the first time path than under the second. The intuition is the following. The difference between the expected discounted value of being employed without having reported an accident, V_E, and the discounted value while having reported an accident, V_A, is determined by the expected duration until unemployment. Once a worker has reported an accident, he is expected to become unemployed sooner (since $\delta_A > \delta_E$) so a reduction in the value of becoming unemployed (while controlling for long run level effects) at $t = 0$ has a bigger negative effect on V_A then on V_E. Hence, $V_E(0) - V_A(0)$ increases as V_u falls faster at $t = 0$ and fewer accidents are reported.

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 $u(.)$, on the number of reported accidents. The remainder of this section links the development of $u(.)$ to the development of

$V_u(.)$. 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 $V_u(.)$ is determined by the following differential equation

$$\rho V_u(t) = b + q(u(t))[V_E(t) - V_u(t)] + \dot{V}_u(t) \tag{4}$$

where b is the unemployment benefit level and $q(.)$ 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 $q(.)$ is as a matching probability, where the number of matches each period equals $m(u(t), v(t))$ for some matching function $m(.,.)$ 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. (2001)). 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 $q'(u) < 0$. Below we consider different time paths for $u(.)$, keeping the function $q(.)$ the same.

Since $V_u(t)$ is decreasing in $u(t)$, we can formulate the results in the propositions above as follows.

Corollary 3 *Consider two steady state unemployment levels u and $u+\varepsilon$. Then $\varepsilon > 0$ implies that the number of accidents reported in the alternative steady state is lower than the number of accidents reported in the original steady state.*

Consider two time paths $u_1(t)$ and $u_2(t)$ with

$$\begin{aligned} u_1(0) &= u_2(0) \\ u_1(t) &= u_2(t) \text{ for all } t \geq T \end{aligned}$$

for some $T > 0$. These time paths induce time paths for V_{u1} and V_{u2} resp. that satisfy

$$\begin{aligned} V_{u_1}(0) &= V_{u_2}(0) \\ \bar{V}_{u1}^{\rho+\delta_a}(0) &= \bar{V}_{u2}^{\rho+\delta_a}(0) \end{aligned}$$

Then $\dot{u}_1(0) < \dot{u}_2(0)$ implies that the number of reported accidents at $t = 0$ is lower under time path $u_2(.)$ than under $u_1(.)$.

Hence we see that a higher unemployment level leads to fewer reported accidents. When considering the effect of a change in unemployment level, we need to correct again for level effects (as in proposition 2). This takes the form here that at $t = 0$ the unemployment level is the same for both series. Further, from some future date $T > 0$ onwards, the unemployment levels coincide for both series. Yet, this is not enough to remove level effects, as it does not exclude the case where $u_1(t) < u_2(t)$ for all $t \in \langle 0, T \rangle$ and path 2 is unambiguously worse for a worker than path 1. The two conditions on the value of being unemployed removes these level effects. If unemployment rises faster at $t = 0$ under time path 2 than under 1, then the value of being unemployed initially falls faster under time path 2 than under 1 ($\dot{V}_{u2}(0) < \dot{V}_{u1}(0)$) since it is relatively harder to find a job. Proposition 2 then implies that fewer accidents are reported under time path 2 than under 1. Summarizing, we find a smaller number of accidents reported when unemployment rises.

4 Workplace accidents across the OECD

4.1 Data

There are clear differences in the ways in which countries define and register workplace accidents. 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.[8] To give some examples for the year 1995: in Canada there were about 410,000 workplace accidents of which 750 were fatal, France had 670,000 workplace accidents of which 700 were fatal, Italy had 660,000 workplace accidents of which 1150 were fatal, Spain had 600,000 workplace accidents of with 1000 were fatal, UK had 150,000 workplace accidents of which 230 were fatal and the US had 2.8 million workplace accidents of which 6300 were fatal. The appendix provides more details about the data.

Figure 2 shows the evolution of (non-fatal) workplace accident rates and unemployment rates for the 17 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

[8] According to the European Agency for Safety and Health at Work depending on the reporting procedure (insurance or non-insurance based systems) the reporting levels for accidents at work differ. In general, the reporting levels are very high in the insurance based systems and considered to be about 100%. The non-insurance based system has only a medium reporting level usually ranging from 30 to 50%, on average, for all branches of economic activity taken together.

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. After that both the unemployment rate and the workplace accident rate have gone down.

Table 1 gives a summary presentation of workplace accidents rates - both fatal and non-fatal - across the OECD. As is obvious there is a big range in accident rates, from as low as 0.4% in Ireland to 8.1% in Belgium and 9.6% in Luxembourg. These differences partly have to do with the definition of workplace accidents. In Ireland and the UK for example workplace accidents refer to incapacity of the worker of 4 workdays or more. In Austria and Portugal for example workplace accidents include non-fatal cases without lost workdays. Also for fatal workplace accidents there is a wide difference between countries from a low 0.001% in the Netherlands to a high 0.011% in Luxembourg. Over the same calendar time period the unemployment rate varied from 1.7% in Luxembourg to 18.9% 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. The fourth column of Table 1 shows that in most countries there is a significant negative correlation between both rates. Only for Denmark, the UK and the US there is a positive but insignificant correlation between both rates. The last column of Table 1 shows the correlation between the fatal accident rates and the unemployment rates for each of the countries involved. Here too there is frequently a significant negative correlation. Of course both the correlation between unemployment and (non-fatal) workplace accidents and the correlation between unemployment and fatal workplace accidents may be based on trendlike developments, with unem-

ployment going up in many countries and workplace accidents going down. In order to accounts for these trends we have to perform a multivariate analysis, which is presented in the next section.

4.2 Parameter estimates

Our empirical analysis is based on the relationship between reported workplace accidents and unemployment rates, which we derived in the theoretical section. As discussed in the previous section countries differ in the way they register and collect data on workplace accidents. This means that fixed differences between countries in workplace accidents rates may occur.[9] 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 also calendar years and country specific time trends to the relationship:

$$\ln(a_{i,t}) = \beta_{0i} + \beta_{0t} + \beta_{1i}\tau + \beta_2 \ln(u_{i,t}) + \varepsilon_{i,t} \tag{5}$$

where a is the (non fatal) workplace accident rate, τ 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 the

[9] 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 accidents than the average worker, irrespective of whether they had a temporary or permanent contract. Furthermore, the risk of an accidents for people aged between 18 and 24 was 1.4 times the average. Also, there are big differences between industries. In agriculture, hunting and fishing the accident rate was 6.8%, in construction 8.3%.

appendix for details). To account for possible heteroskedasticity we calculated robust standard errors.

The estimation results are shown in Table 2. The upper part of this table concerns the estimation results when we take all information into account and use 356 datapoints for 17 countries. We show parameter estimates of β_2 with and without country-specific time trends. The first column shows that the elasticity of workplace accidents with respect to unemployment equals -0.11. This elasticity goes down to -0.16 if country-specific time trends are included. It is obvious that the unemployment rate has a significant negative effect on non-fatal accidents. For fatal accidents we estimate similar equations as (1). The third column shows that also fatal workplace accidents seem to be influenced by the unemployment rate. However, if we introduce country-specific time trends the elasticity is not different from zero at conventional levels of significance.

The middle part of Table 2 shows the estimation results if we reduce the sample to EU-countries, in which case we have 301 datapoints for 14 countries. As shown the parameter estimates are not much affected by this reduction. The lower part of Table 2 shows the estimation results if we use a balanced sample for the period 1980-86, in which case we have 204 datapoints for 12 countries (11 EU-countries and the US). Again, the parameter estimates do not change a lot. It is clear that the unemployment rate has a significantly negative effect on the non-fatal accidents rate while it does not affect the fatal accident rate.

The lower part of Table 2 also contains sensitivity analyses, where we first introduce the hours actually worked per person employed as potentially explanatory variable.

$$\ln(a_{i,t}) = \beta_{0i} + \beta_{0t} + \beta_{1i}\tau + \beta_2 \ln(u_{i,t}) + \beta_3 \ln(h_{i,t}) + v_{i,t} \qquad (6)$$

where h is the hours actually work per person employed and $v_{i,t}$ are the error terms. As shown the estimation results hardly change. In the regressions with the non-fatal accident rate as dependent variable the coefficient on working hours is negative and highly insignificant. In the regressions with the fatal accident rate as dependent variable the coefficient on working hours is positive though not significantly different from zero. Apparently the number of working hours neither affect non-fatal workplace accidents nor fatal workplace accidents.

Then we subsequently add the change in the unemployment rate and the change in employment as potential explanatory variables:

$$\ln(a_{i,t}) = \beta_{0i} + \beta_{0t} + \beta_{1i}\tau + \beta_2 \ln(u_{i,t}) + \beta_4 \Delta \ln(u_{i,t}) + \beta_5 \Delta \ln(e_{i,t}) + v_{i,t} \quad (7)$$

where e is employment, Δ the indicator for first differences and $v_{i,t}$ are the error terms.

If we introduce the change in unemployment rate as additional explanatory variable the elasticity of non-fatal workplace accidents with respect to unemployment drops a little bit from -0.19 to -0.16 while the change in unemployment also has a significant negative effect on the accident rate. If we add the change in employment rate as explanatory variable we find that this variable has no significant effect on the accident rate while the effects of unemployment and change in unemployment hardly change. The estimates with country-specific time trends are very similar. If we introduce the change in unemployment rate as additional explanatory variable the elasticity of fatal workplace accidents is still insignificantly different from zero. The change in unemployment has a significant negative effect but this effects vanishes if we introduce country-specific time trends.

So high unemployment rates and increases in unemployment rates have a significant negative effect on workplace accident rates whereas changes in employment do not affect 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 3 shows country-specific estimates of β_2. For each of the 12 countries in the balanced sample $\widehat{\beta}_2 < 0$, although the values range from a high and insignificant -0.10 for Denmark to a low -0.77 for France. Clearly β_2 is heterogenous parameter. Table 4 shows estimation results we impose restrictions on the country-specific parameter estimates of β_2. The first column shows parameter estimates if we estimate β_2 for 3 groups of countries. The largest group has a $\widehat{\beta}_2$ of -0.17, while for the second group $\widehat{\beta}_2 = -0.70$ and for the third group $\widehat{\beta}_2 = -0.34$. From a Likelihood Ratio test comparing the restricted estimates with the fully flexible parameter estimates of Table 2 it appears that we cannot reject the restriction that there are 3 different types of countries.[10] The second column of Table 4 shows estimation results if we assume β_2 to be a random coefficient with a discrete distribution that has two points of support β_{2a} and β_{2b} and mass points p and $1-p$.[11] The estimation results indicate that $\widehat{\beta}_{2a} = -0.20$ with a probability-mass of 88% and $\widehat{\beta}_{2b} = -0.11$, with a probability-mass of 12%. Again, from a LR-test it appears that we cannot reject the reduction of the 12 country-specific β_2's to 2 β_2's, that are both significantly smaller than zero. All in all, although there is some parameter heterogeneity it is clear that the unemployment rate has a significant negative effect on the non-fatal accident rate.

[10] We investigated whether the country-specific coefficients β_2 are correlated with the country-specific unemployment benefit replacement rates, but found this not to be the case.

[11] The parameters of this mixing distribution are estimated using maximum likelihood.

5 Conclusions

In this paper we develop a theoretical model to explain cyclical fluctuations in workplace accidents. We distinguish between two possible explanations, workplace conditions and reporting behavior. The 'workplace conditions' explanation predicts that the level of unemployment is negatively related to workplace accidents because effort is negatively related to unemployment. Furthermore, it predicts that working hours are positively related to workplace accidents because working longer increases the probability of an accidents to occur. 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 both the level and the change in unemployment are negatively related to workplace accidents. Another distinction between the two alternative explanations has to do with fatal accidents. If cycles in workplace conditions 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 with fatal accidents there is no reporting decision.

In our empirical analysis based on information from OECD countries we find that workplace accidents are inversely related to both the level of unemployment and the change in unemployment, while working hours and changes in employment do not affect accidents rates. Furthermore, fatal accident rates do not seem to be related to labor market conditions. From all this we conclude that the cyclical fluctuations in workplace accidents have to do with reporting behavior of workers. If unemployment is high or increasing workers are less likely to report about workplace accidents than they are in situations of low or decreasing un-

employment. We find no evidence that working conditions deteriorate in cyclical upturns. Workplace safety does not change over the cycle. Therefore variations in workplace accidents statistics should be treated with caution. In particular, there is no point in launching a workplace safety campaign when the number of reported accidents goes up in an upturn. Instead, one should concentrate efforts on encouraging workers to report accidents in a slump.

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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. Table A1 describes some general characteristics of the information on workplace accidents.

Table A1 Information about workplace accidents in country statistics[a)]

	Source & subject	Minimum period (days)	Commuting accidents	Breaks in series
1 Austria	FA - 81	0	yes	1985-86
2. Belgium	FA - 82	0	yes	-
3. Canada	FA - 82	1	no	-
4. Denmark	FF - 82	1	no	1982-83
5. Finland	FA - 81	3	no	-
6. France	FA - 82	1	no	-
7. Germany	FA - 82	3	no	1990-91
8. Ireland	FF - 81	4	no	1992-93
9. Italy	FA - 82	3	yes	1989-90
10. Luxembourg	FA - 82	0	no	-
11. Netherlands	FA - 81	0	no	-
12. Portugal	FA - 81	0	no	-
13. Spain	FA - 81	1	no	-
14. Sweden	FA - 81	1	no	1990-91
15. Switzerland	FA - 82	1	no	-
16. UK	FF - 81	4	no	1989-90
17. US	DA - 81	1	no	-

[a)] ILO classification. Source: DA = labor related establishment survey, FA = insurance records, FF = labor inspectorate records. Subject: 81 = reported, 82 = compensated. Denmark 1978-90 source = 82. Germany until 1991: West-Germany

Table A2 gives the sources of information for the data.

Table A2 Sources of data[a)]

	Non-fatal accidents	Fatal accidents	Unemployment	Employment
1. Austria	national	ILO	ILO	GGDC
2. Belgium	national	ILO	ILO	ILO
3. Canada	ILO	ILO	ILO	GGDC
4. Denmark	ILO, national	ILO	ILO	GGDC
5. Finland	ILO	ILO	ILO	ILO
6. France	ILO, national	ILO, national	ILO	ILO
7. Germany	ILO, national	ILO, national	national	GGDC
8. Ireland	ILO	ILO	national	ILO
9. Italy	ILO	ILO	ILO	ILO
10. Luxembourg	national	national	ILO	ILO
11. Netherlands	ILO, national	ILO	ILO	GGDC
12. Portugal	ILO	ILO	ILO	GGDC
13. Spain	ILO	ILO	ILO	GGDC
14. Sweden	ILO, national	ILO, national	ILO	ILO
15. Switzerland	ILO	ILO	ILO	ILO
16. UK	ILO	ILO	ILO	ILO
17 .US	ILO	ILO	ILO	ILO

[a)] ILO: Bureau of Statistics (LABORSTA)

National: various national statistics

GGDC: University of Groningen and The Conference Board, Growth & Development Centre Total Economy Database, 2002, http://www.eco.rug.nl/ggdc

The information about hours actually worked per employee is from the GGDC.

Since this dataset does not contain the information about working hours from Luxembourg we have replaced this series with information about Belgium.

7 Appendix 2: Proof of results

We begin this appendix 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 4 *Let $g(.)$ be a real valued function of $t \in \Re$ with $|g(.)| < M$ for some $M > 0$. Consider the differential equation*

$$\psi h(t) = g(t) + \dot{h}(t) \tag{8}$$

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 (8) 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 (8), 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 (8)

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

Q.E.D.

Lemma 5 *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*

$$\overline{\bar{g}^{\delta}}^{\psi}(t) \equiv \psi \int_t^{+\infty} e^{-\psi(s-t)} \bar{g}^{\delta}(s) \, ds = \frac{\bar{g}^{\delta}(t) - \frac{\delta}{\psi} \bar{g}^{\psi}(t)}{1 - \frac{\delta}{\psi}} \tag{9}$$

for $\psi > 0$.

Proof

Using integration by parts we get

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

and hence the result in equation (9) follows. Q.E.D.

Lemma 6 *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*

$$V_A(t) = \frac{w+\phi\int_0^{+\infty}[-\alpha+\gamma(\alpha)]f(\alpha)\,d\alpha}{\rho+\delta_A}+\frac{\delta_A}{\rho+\delta_A}\bar{V}_u^{\rho+\delta_A}(t) \quad (10)$$

$$\begin{aligned}
V_E(t)-V_A(t) &= \frac{-\phi\int_0^{\bar{\alpha}}\gamma(\alpha)f(\alpha)\,d\alpha+(\delta_A-\delta_E)\frac{w+\phi\int_0^{+\infty}[-\alpha+\gamma(\alpha)]f(\alpha)d\alpha}{\rho+\delta_A}}{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}+\\
&\quad\frac{(\delta_A-\delta_E)\,\bar{g}^{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}(t)}{\rho+\delta_E+\phi(1-F(\bar{\alpha}))} \qquad (11)
\end{aligned}$$

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

$$g(t)\equiv\frac{\delta_A}{\rho+\delta_A}\bar{V}_u^{\rho+\delta_A}(t)-V_u(t) \qquad (12)$$

Proof

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

$$(\rho+\delta_A)V_A(t)=w+\phi\int_0^{+\infty}[-\alpha+\gamma(\alpha)]f(\alpha)\,d\alpha+\delta_A V_u(t)+\dot{V}_A(t) \quad (13)$$

we see it is a differential equation of the form (8). Hence lemma 4 implies that the solution can be written as equation (10).

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

$$\begin{aligned}(\rho + \delta_E) V_E(t) &= w - \phi \int_0^{+\infty} \alpha f(\alpha)\, d\alpha + \phi \int_{\bar{\alpha}}^{+\infty} [\gamma(\alpha) - (V_E(t) - V_A(t))] f(\alpha)\, d\alpha + \\ &\quad \delta_E V_u(t) + \dot{V}_E(t) \end{aligned} \tag{14}$$

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

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

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

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

Subtracting from (14) equation (13), we get

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

Defining $\Delta_{EA}(t) \equiv V_E(t) - V_A(t)$ and substituting into this equation the solution for $V_A(t)$ in equation (10) we find

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

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 (8). Applying the solution in lemma 4 gives us equation (11) above. Q.E.D.

Proof of proposition 1

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 (11), a sufficient condition for this is that $g(t)$ as defined in equation (12) 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

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

Q.E.D.

Proof of proposition 2

To simplify notation later on, define the function $\varepsilon(t)$ as the difference between the two time paths, that is

$$\varepsilon(t) \equiv V_{u2}(t) - V_{u1}(t)$$

Then the conditions in the proposition can be written as

$$\begin{aligned} \varepsilon(0) &= 0 \\ \bar{\varepsilon}^{\rho+\delta_A}(0) &= 0 \\ \varepsilon'(0) &< 0 \end{aligned}$$

and there exists $T > 0$ such that

$$\varepsilon(t) = 0 \text{ for all } t \geq T$$

On the basis of this, we have to show that $\Delta_{AE}(0)$ is bigger under time path V_{u2} than under V_{u1} (because that implies that more accidents are reported at time $t=0$ under V_{u1} than under V_{u2}). Similar to the proof of proposition 1, we need to consider the difference between the function $g(.)$ (as defined in (12)) under time path V_{u2}, denoted by $g_{\varepsilon}(t)$, and under time path V_{u1}, denoted $g_{\mathbf{0}}(t)$. It is routine to verify that this difference can be written as

$$\begin{aligned} g_{\varepsilon}(t) - g_{\mathbf{0}}(t) &= \left[\frac{\delta_A}{\rho+\delta_A}\left(\bar{V}_{u1}^{\rho+\delta_A}(t) + \bar{\varepsilon}^{\rho+\delta_A}(t)\right) - (V_{u1}(t) + \varepsilon(t))\right] \\ &\quad - \left[\frac{\delta_A}{\rho+\delta_A}\bar{V}_{u1}^{\rho+\delta_A}(t) - V_{u1}(t)\right] \\ &= \frac{\delta_A}{\rho+\delta_A}\bar{\varepsilon}^{\rho+\delta_A}(t) - \varepsilon(t) \end{aligned}$$

It follows that $\Delta_{AE}(0)$ is bigger under time path V_{u2} than under V_{u1} if and only if

$$(\rho+\delta_E+\phi(1-F(\bar{\alpha})))\int_{\mathbf{0}}^{+\infty} e^{-(\rho+\delta_E+\phi(1-F(\bar{\alpha})))t}\left[\frac{\delta_A}{\rho+\delta_A}\bar{\varepsilon}^{\rho+\delta_A}(t) - \varepsilon(t)\right]dt > 0 \quad (15)$$

Using lemma 5 above, we find that

$$\begin{aligned} &\frac{\delta_A}{\rho+\delta_A}\overline{\bar{\varepsilon}^{\rho+\delta_A}}^{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}(0) \\ =\ &\frac{\delta_A}{\rho+\delta_A}(\rho+\delta_E+\phi(1-F(\bar{\alpha})))\int_{\mathbf{0}}^{+\infty} e^{-(\rho+\delta_E+\phi(1-F(\bar{\alpha})))t}\bar{\varepsilon}^{\rho+\delta_A}(t)\,dt \\ =\ &\frac{\delta_A}{\rho+\delta_A}\frac{\bar{\varepsilon}^{\rho+\delta_A}(0) - \frac{\rho+\delta_A}{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}\bar{\varepsilon}^{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}(0)}{1-\frac{\rho+\delta_A}{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}} \end{aligned} \quad (16)$$

Using the condition above that $\bar{\varepsilon}^{\rho+\delta_A}(0)=0$, we can rewrite inequality (15) as

$$-\frac{\delta_A}{\rho+\delta_A}\frac{\frac{\rho+\delta_A}{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}\bar{\varepsilon}^{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}(0)}{1-\frac{\rho+\delta_A}{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}} - \bar{\varepsilon}^{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}(0) > 0$$

or equivalently

$$\bar{\varepsilon}^{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}(0)\left[-\frac{\delta_A}{\rho+\delta_A}\frac{\frac{\rho+\delta_A}{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}}{1-\frac{\rho+\delta_A}{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}} - 1\right] > 0$$

which can be written as

$$\frac{\delta_E + \phi\left(1 - F\left(\bar{\alpha}\right)\right)}{\delta_A}\left[\overline{\bar{\varepsilon}^{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}}\left(0\right)\frac{\delta_A}{\left(\delta_A - \delta_E\right) - \phi\left(1 - F\left(\bar{\alpha}\right)\right)}\right] > 0 \quad (17)$$

Clearly the fraction $\frac{\delta_E+\phi(1-F(\bar{\alpha}))}{\delta_A}$ is strictly positive. So the remainder of this proof shows that the term between square brackets is positive.

Return to the expression for $\frac{\delta_A}{\rho+\delta_A} \times \overline{\bar{\varepsilon}^{\rho+\delta_A}}^{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}\left(0\right)$ in equation (16). The expression $\overline{\bar{\varepsilon}^{\rho+\delta_A}}^{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}\left(0\right)$ is the weighted average of the future values of $\bar{\varepsilon}^{\rho+\delta_A}$ as of time 0 (where the weights follow an exponential distribution with parameter $\rho + \delta_E + \phi\left(1 - F\left(\bar{\alpha}\right)\right)$). The following lemma shows that $\bar{\varepsilon}^{\rho+\delta_A}\left(t\right)$ is nonnegative for all $t \geq 0$ and strictly positive for some $t \geq 0$. Hence the weighted average of $\bar{\varepsilon}^{\rho+\delta_A}$ as of time 0 is strictly positive as well, that is $\overline{\bar{\varepsilon}^{\rho+\delta_A}}^{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}\left(0\right) > 0$, which we use below.

Lemma 7 *It is the case that*

$$\begin{aligned} \bar{\varepsilon}^{\rho+\delta_A}\left(t\right) &\geq 0 \text{ for all } t \geq 0 \\ \bar{\varepsilon}^{\rho+\delta_A}\left(t\right) &> 0 \text{ for } t \in \langle 0, T\rangle \end{aligned}$$

Hence we find that

$$\begin{aligned} \overline{\bar{\varepsilon}^{\rho+\delta_A}}^{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}\left(0\right) &= \left(\rho + \delta_E + \phi\left(1 - F\left(\bar{\alpha}\right)\right)\right)\int_0^{+\infty} e^{-(\rho+\delta_E+\phi(1-F(\bar{\alpha})))t}\bar{\varepsilon}^{\rho+\delta_A}\left(t\right) \quad (18) \\ &> 0 \end{aligned}$$

Proof of Lemma 7

Consider figure 1 which shows a path for $\varepsilon\left(t\right)$ satisfying the conditions in the lemma above. Since $\varepsilon\left(t\right) \geq 0$ for all $t \geq t_2$ and $\varepsilon\left(t\right) > 0$ for all $t \in \langle t_2, T\rangle$ it is clear that $\bar{\varepsilon}^{\rho+\delta_A}\left(t\right) > 0$ for $t \in [t_2, T\rangle$. We need to prove that $\bar{\varepsilon}^{\rho+\delta_A}\left(t\right) \geq 0$ for $t \in \langle 0, t_2\rangle$. This we prove by contradiction. Suppose not, that is suppose that $\bar{\varepsilon}^{\rho+\delta_A}\left(t_1\right) < 0$ for some $t_1 \in \langle 0, t_2\rangle$ (see figure 1), then by continuity of $\bar{\varepsilon}^{\rho+\delta_A}\left(t\right)$ the

intermediate value theorem implies that there exists $\bar{t} \in \langle t_1, t_2 \rangle$ such that $\bar{\varepsilon}^{\rho+\delta_A}(\bar{t}) = 0$. We can now write $\bar{\varepsilon}^{\rho+\delta_A}(0)$ as

$$\begin{aligned}
\bar{\varepsilon}^{\rho+\delta_A}(0) &= (\rho+\delta_A)\int_0^{\bar{t}} e^{-(\rho+\delta_A)t}\varepsilon(t)\,dt + (\rho+\delta_A)\,e^{-(\rho+\delta_A)\bar{t}}\int_{\bar{t}}^{+\infty} e^{-(\rho+\delta_A)(t-\bar{t})}\varepsilon(t)\,dt \\
&= (\rho+\delta_A)\int_0^{\bar{t}} e^{-(\rho+\delta_A)t}\varepsilon(t)\,dt + e^{-(\rho+\delta_A)\bar{t}}\bar{\varepsilon}^{\rho+\delta_A}(\bar{t}) \\
&= (\rho+\delta_A)\int_0^{\bar{t}} e^{-(\rho+\delta_A)t}\varepsilon(t)\,dt
\end{aligned}$$

because by definition of $\bar{t}$ we have $\bar{\varepsilon}^{\rho+\delta_A}(\bar{t}) = 0$. However, since $\varepsilon(t) < 0$ for all $t \in \langle 0, t_2 \rangle$ (see figure 1) these equations imply that $\bar{\varepsilon}^{\rho+\delta_A}(0) < 0$ which contradicts our assumption on $\varepsilon(t)$ that $\bar{\varepsilon}^{\rho+\delta_A}(0) = 0$. Hence, there cannot be a value $t_1 \in \langle 0, t_2 \rangle$ such that $\bar{\varepsilon}^{\rho+\delta_A}(t_1) < 0$. Consequently, $\bar{\varepsilon}^{\rho+\delta_A}(t) \geq 0$ for $t \in \langle 0, t_2 \rangle$, which we needed to prove.

Since $\overline{\bar{\varepsilon}^{\rho+\delta_A}}^{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}(0)$ is the weighted average of a variable that is non-negative everywhere and strictly positive for some $t > 0$ we find that $\overline{\bar{\varepsilon}^{\rho+\delta_A}}^{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}(0) > 0$. Q.E.D. (Lemma 7)

Using inequality (18) in (16) we find that

$$-\frac{\delta_A}{\rho+\delta_A}\frac{\frac{\rho+\delta_A}{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}\bar{\varepsilon}^{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}(0)}{1-\frac{\rho+\delta_A}{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}} > 0$$

It is routine to verify that this inequality can be rewritten as

$$\bar{\varepsilon}^{\rho+\delta_E+\phi(1-F(\bar{\alpha}))}(0)\frac{\delta_A}{(\delta_A-\delta_E)-\phi(1-F(\bar{\alpha}))} > 0$$

This is exactly the square bracketed term in equation (17), which we have now proved to be positive. Q.E.D. (Proposition 2)

8 Tables and graphs

Table 1 Stylized facts about workplace accidents and labor markets[a)]

	a	fa	u	correlation coefficient	
	(%)	(0.1%)	(%)	a-u	fa-u
1. Austria	6.8 (20)	0.08 (25)	4.4	-0.90*	-0.81*
2. Belgium	8.1 (28)	0.04 (15)	9.8	-0.94*	0.44
3. Canada	3.8 (15)	0.06 (15)	9.3	-0.13	-0.42
4. Denmark	1.6 (27)	0.03 (22)	8.1	0.14	-0.28
5. Finland	4.0 (23)	0.04 (23)	7.8	-0.86*	-0.48*
6. France	4.0 (30)	0.07 (30)	8.0	-0.99*	-0.98*
7. Germany	6.2 (30)	0.08 (30)	5.6	-0.94*	-0.78*
8. Ireland	0.4 (24)	0.03 (24)	12.5	-0.60*	0.03
9. Italy	4.0 (21)	0.07 (21)	10.5	-0.60*	-0.67*
10. Luxembourg	9.6 (29)	0.11 (29)	1.7	-0.93*	-0.78*
11. Netherlands	1.6 (23)	0.01 (14)	6.7	-0.73*	-0.65*
12. Portugal	6.2 (18)	0.08 (20)	6.8	-0.16	0.56*
13. Spain	5.0 (20)	0.10 (20)	18.9	-0.44*	-0.37*
14. Sweden	2.1 (30)	0.03 (28)	3.6	-0.36*	-0.24
15. Switzerland	3.3 (16)	0.03 (16)	2.4	-0.88*	-0.83*
16. UK	0.7 (14)	0.01 (19)	8.0	0.31	0.49*
17. US	2.4 (24)	0.04 (24)	6.5	0.06	-0.12

[a)] In the calculation of the correlations breaks in the series have been taken into account; * indicates that the correlation is significantly different from zero at a 5% level. The numbers in parentheses refer to the number of observations on which the calculation is based. The averages for the unemployment rate are calculated for the same year as the averages for the non-fatal workplace accidents rate.

Table 2 Estimation results (t- values in parentheses)[a)]

All (356 observations, 17 countries)

	non-fatal accidents		fatal accidents	
	(1)	(2)	(3)	(4)
$\ln(u)$	-0.109 (5.9)	-0.164 (8.7)	-0.160 (4.0)	-0.092 (1.6)
country t.t.	no	yes	no	yes

EU countries (301 observations, 14 countries)

	non-fatal accidents		fatal accidents	
	(1)	(2)	(3)	(4)
$\ln(u)$	-0.092 (4.0)	-0.187 (9.6)	-0.082 (1.7)	-0.063 (1.0)
country t.t.	no	yes	no	yes

Balanced panel, 1980-96 (204 observations, 12 countries)

	non-fatal accidents		fatal accidents	
	(1)	(2)	(3)	(4)
$\ln(u)$	-0.186 (6.2)	-0.209 (5.9)	-0.104 (1.1)	-0.144 (1.3)
$\ln(u)$	-0.186 (6.2)	-0.209 (5.9)	-0.108 (1.2)	-0.155 (1.4)
$\ln(h)$	-0.005 (0.2)	0.005 (0.2)	0.190 (1.5)	0.125 (1.3)
$\ln(u)$	-0.159 (5.2)	-0.181 (5.4)	-0.055 (0.6)	-0.115 (1.1)
$\Delta \ln(u)$	-0.211 (3.7)	-0.137 (3.0)	-0.280 (2.2)	-0.142 (1.0)
$\ln(u)$	-0.159 (5.2)	-0.180 (5.3)	-0.055 (0.6)	-0.116 (1.1)
$\Delta \ln(u)$	-0.215 (3.4)	-0.166 (3.4)	-0.369 (1.9)	-0.131 (0.8)
$\Delta \ln(e)$	-0.001 (0.1)	-0.003 (1.7)	0.001 (0.1)	0.001 (0.1)
country t.t.	no	yes	no	yes

[a)] u is unemployment rate, h is average number of working hours per employee, e is employment rate; t-values based on robust standard errors in parentheses; country fixed effects, year fixed effects, country time trends and dummy variables for some countries are included

Table 3 Sensitivity analysis, country-specific coefficients of ln(u); balanced panel 1980-96[a)]

	Non-fatal accidents	Fatal accidents
Austria	-0.153 (3.3)	-0.561 (4.1)
Denmark	-0.101 (0.5)	-0.264 (1.0)
Finland	-0.177 (8.5)	-0.066 (0.8)
France	-0.773 (6.2)	-0.729 (2.4)
Germany	-0.271 (5.9)	-0.020 (0.1)
Ireland	-0.146 (1.7)	-1.810 (5.4)
Italy	-0.113 (0.3)	-0.341 (0.8)
Luxembourg	-0.166 (4.1)	-0.048 (0.2)
Portugal	-0.367 (6.9)	0.673 (3.7)
Spain	-0.648 (9.7)	-0.269 (1.3)
Sweden	-0.199 (3.2)	-0.170 (1.3)
US	-0.398 (4.7)	0.569 (1.4)

[a)] t-statistics based on robust standard errors in parentheses

Table 4 Additional estimates for workplace accidents, coefficients of ln(u), balanced panel 1980-96[a)]

Group fixed effects[b)]		Random effects	
Group 1	-0.172 (6.3)	β_{2a}	-0.199 (8.6)
Group 2	-0.695 (10.1)	β_{2b}	-0.106 (4.5)
Group 3	-0.337 (8.2)	p	0.879 (32.2)
LR-test statistic	2.8		8.2

[a)] t-statistics based on robust standard errors in parentheses; The LR-test statistic compares estimation results with those in Table 3; critical $\chi^2_{0.05} - value$ with 9 degrees of freedom = 16.9

[b)] Group 1: Austria, Denmark, Finland, Ireland, Italy, Luxembourg, Sweden; group 2: France, Spain; group 3: Germany, Portugal, US

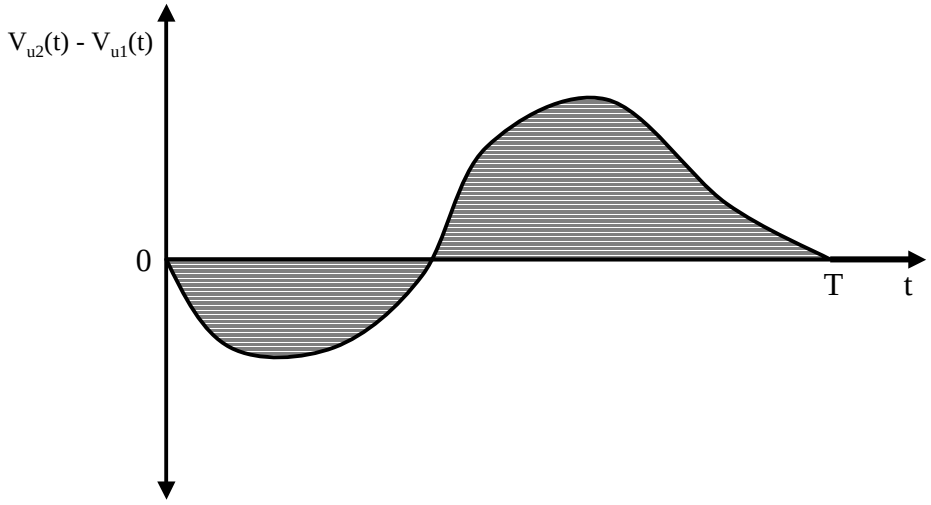
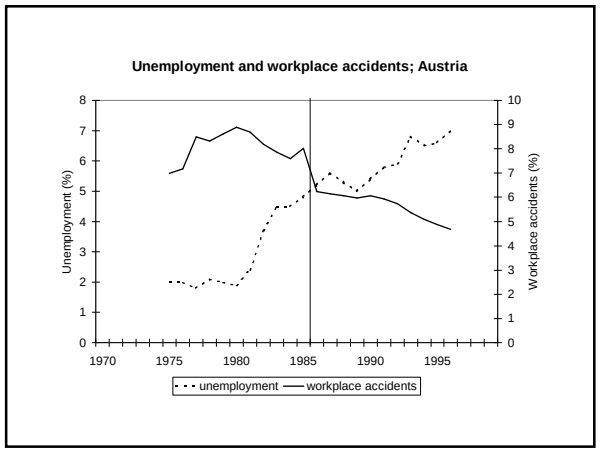
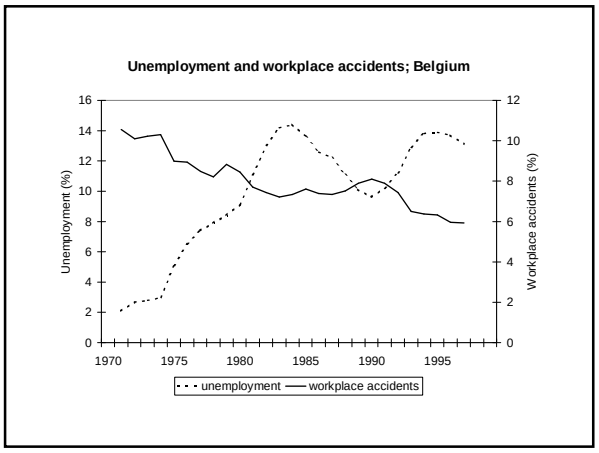
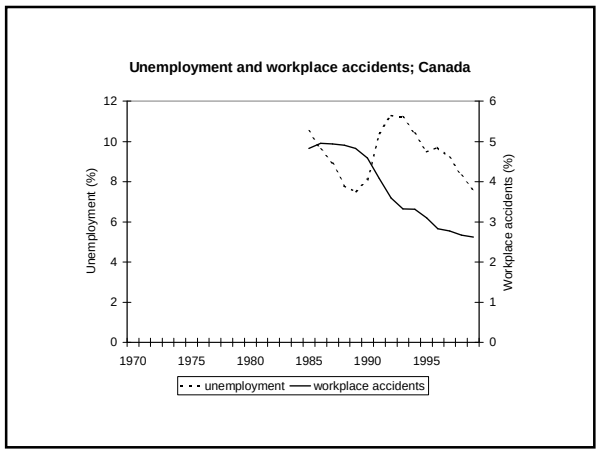


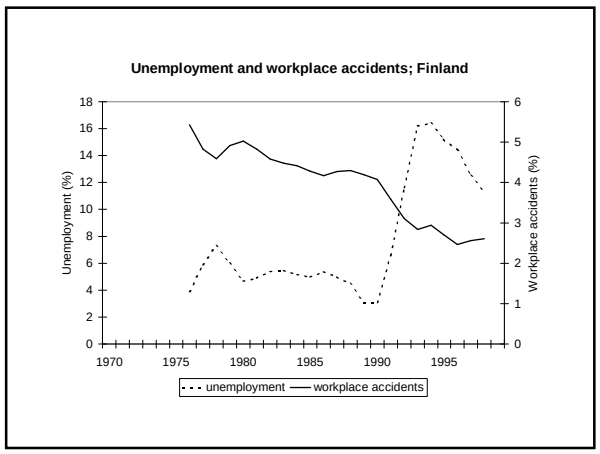
Figure 1: $V_{u2}(t) - V_{u1}(t)$

Figure 2 Unemployment and (non-fatal) workplace accidents in OECD countries; 1970-99









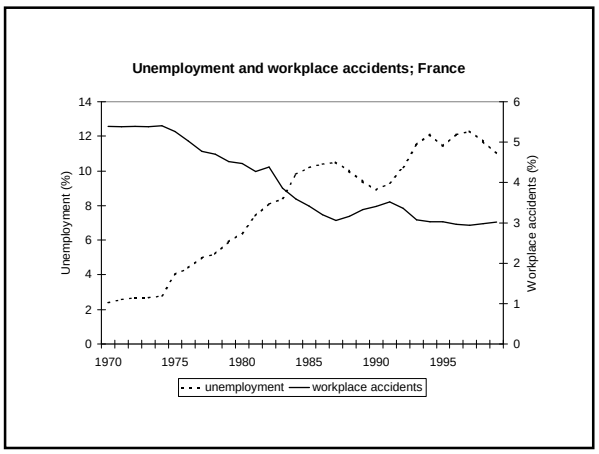
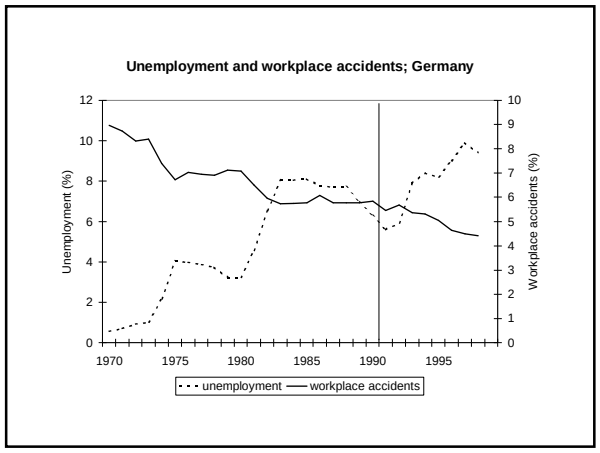
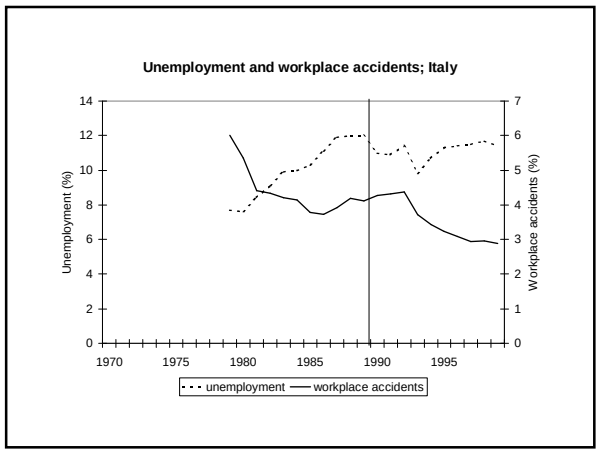
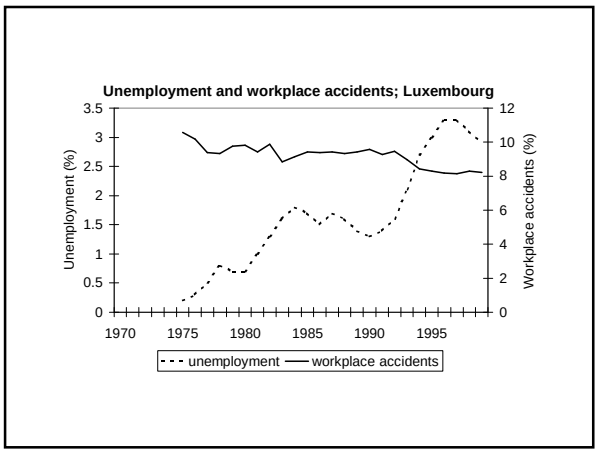
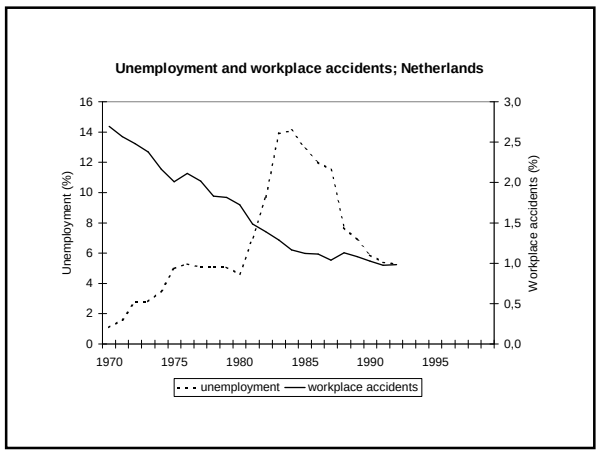


Figure 2 Unemployment and (non-fatal) workplace accidents in OECD countries; 1970-99









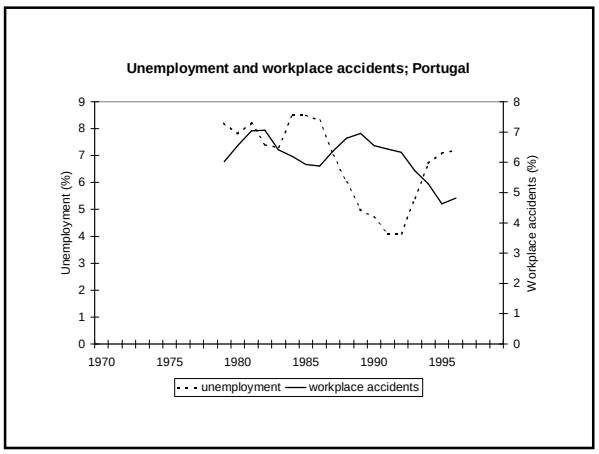
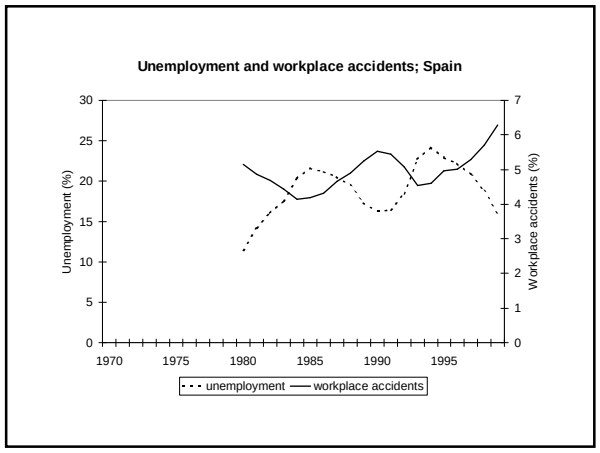
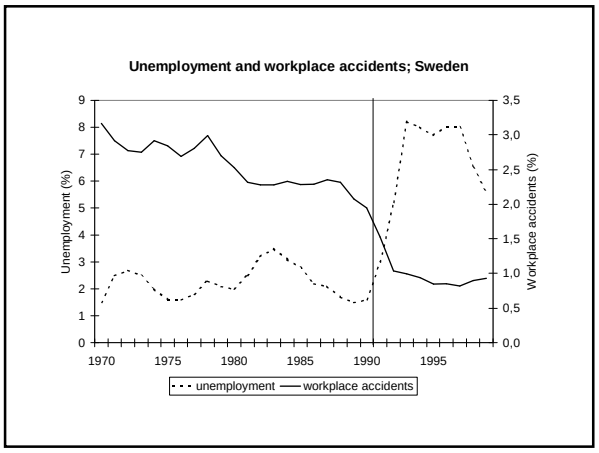
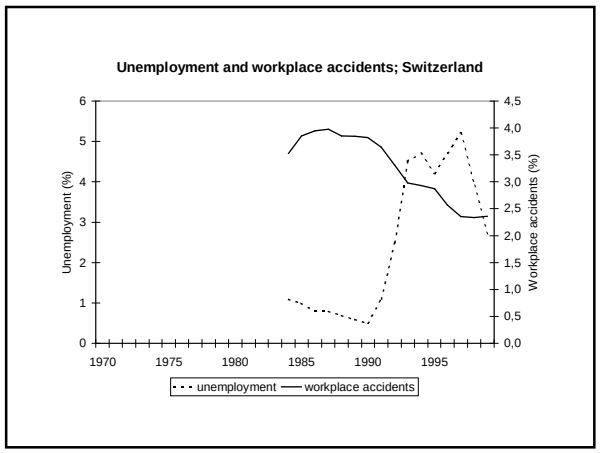
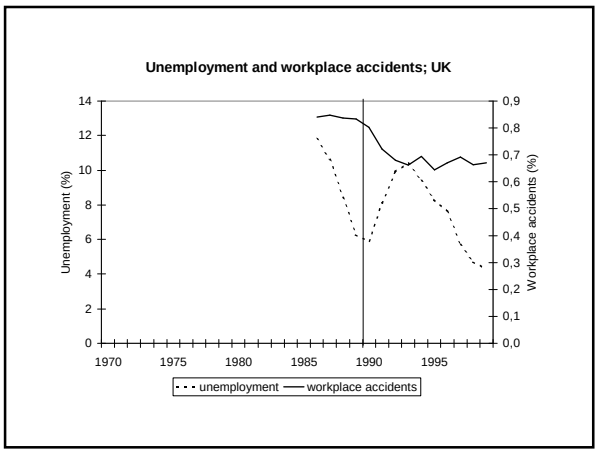
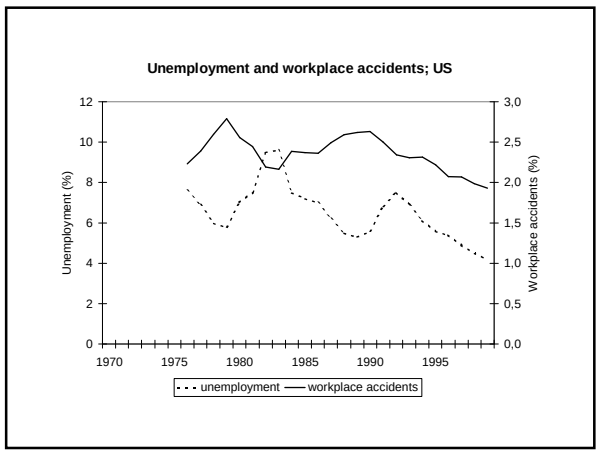



Figure 2 Unemployment and (non-fatal) workplace accidents in OECD countries; 1970-99