Occupational safety in a frictional labor market

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Abstract

Work-related injuries and diseases entail substantial economic costs worldwide. This paper studies the differential effect of search frictions on the provision of occupational safety. Safety measures reduce a firm's current profits but increase future expected output due to lower worker mortality. We find that search frictions reduce the long-run gains of safety measures, which lowers the socially optimal level of occupational safety relative to a frictionless labor market. In a decentralized setting where wages and safety measures are determined at the firm level, matching externalities and a labor supply externality may further reduce safety provision. We obtain conditions under which these externalities are internalized by firms and workers, and discuss the role of policy for promoting occupational safety. The model predicts a positive relation between the equilibrium unemployment rate and work-related mortality, which is verified using US data on fatal occupational injuries.

Keywords: occupational safety, mortality, search frictions, Nash bargaining

JEL classification: J17, J28, J32, J38, J64

1 Introduction

According to the European Agency for Safety and Health at Work (2017a,b), an annual number of 2.8 million deaths worldwide can be attributed to work-related injuries and diseases, amounting to 67.8 million years of life lost. Additionally, non-fatal work-related injuries and diseases cause 55.5 million years lived in disability. Valued by the average production of a worker, the estimated economic costs of fatal and non-fatal incidents sum up to 3.9% of global GDP. Besides the loss in output, work-related injuries and diseases increase financial pressure on public health care systems and social security systems in aging societies. Consequently, safety and health at the workplace have been recognized as key for prolonging working lives and healthy aging, resulting in broad policy initiatives like those of the European Commission (2021a,b) as well as actions specifically targeted at protecting workers from COVID-19 (Biden, 2021).[1]

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[1] In the EU-28, the total costs of work-related injuries and diseases are estimated at 3.3% of GDP (European Agency for Safety and Health at Work, 2017a). Country-specific studies that use more granular cost estimation

From a normative perspective, policy intervention in occupational safety provision can be socially desirable since the level of safety measures arising from the interplay of firm and worker incentives is likely to be inefficient (Henderson, 1983). This is due to the presence of asymmetric information about health risks, psychological biases in the individual perception of risk, as well as externalities on co-workers and society that individual firms and workers fail to take into account.[2] Another inefficiency that so far has not been considered in the context of occupational safety provision are labor market frictions that slow down the matching of unemployed to job openings. Stronger frictions increase the time that unemployed need to find and take up a job. The less frequent they get the opportunity to work, the higher may be their willingness to accept jobs with low safety standards. On the other hand, frictions also increase the time that firms need to fill a vacancy. The longer it takes them to find an applicant for an open position, the higher should be their incentive to safeguard worker health once a match has been formed. Due to these opposing effects, the impact of search frictions on occupational safety is a priori not clear and deserves further investigation.

This paper studies the provision of occupational safety in the presence of search frictions as featured in the workhorse model of modern labor economics, the Diamond-Mortensen-Pissarides (DMP) model. Since occupational safety ultimately affects workers' mortality, we extend the basic DMP model (Pissarides, 2000, Ch. 1) for mortality shocks. The mortality rate of employed individuals is endogenously determined and our main variable of interest. We solve several versions of the model to identify (i) the mortality effect of search frictions and (ii) the mortality effect of externalities relating to matching and bargaining.

By solving the planner's problem with and without frictions, we find that search frictions unambiguously increase the socially optimal mortality rate. The planner essentially compares the current costs of safety measures with their long-term benefits. The latter accrue from a worker's higher life expectancy, which translates into higher lifetime production and utility. Search frictions cause phases of involuntary unemployment, which reduce lifetime production and utility, and therefore lower the long-term benefits of safety measures. Therefore, it is optimal to reduce safety measures and accept higher mortality than in a frictionless labor market.

If safety measures are not centrally mandated but determined bilaterally between workers and firms, mortality may be further elevated due to two externalities. First, private agents may not take into account that a worker who dies on the job is not just lost for its former employer but for the economy as a whole, reducing aggregate labor supply. We find that Nash bargaining generally achieves to internalize this externality, but also present counterexamples. Second, even if the labor supply externality is internalized, the mortality rate is still affected by the matching externalities common to the DMP framework. In this regard, deviations from the familiar Hosios (1990) condition are found to further increase workers' mortality rates, revealing that both too low and too high bargaining power are detrimental to occupational safety.

models report GDP shares of 1% for the UK, 1.8% for the US, 2.9% for Finland, 3.2% for Singapore, 3.5% for Germany and the Netherlands, 4.8% for Australia, 6.3% for Italy, and 10.2% for Poland, see Tompa et al. (2021) and references therein. The large range of estimates is partly due to different cost categories considered.

[2] See Pouliakas and Theodossiou (2013) for a summary of potential distortions.

We also study the potential of policy to increase occupational safety. While implementing a mortality rate below the one chosen by the constrained planner inevitably lowers aggregate output, we demonstrate how to attain a desired mortality rate at the lowest cost. With our optimal policy, the aggregate output loss essentially equals the costs of additional safety measures. Detrimental equilibrium effects on job creation can be neglected as long as the mortality rate targeted by the government remains close to the planner's optimal rate.

The decentralized version of the model predicts a positive relation between the equilibrium unemployment rate and the occupational mortality rate. We verify this prediction by combining mortality data from the Census of Fatal Occupational Injuries (CFOI) and employment data from the Current Population Survey (CPS). The marginal effect of unemployment on occupational mortality is identified from variation across US states within occupations and age groups. The point estimates we obtain from several regression specifications suggest that a one percentage point higher unemployment rate is associated with a 2.0–2.7% higher mortality rate from occupational injuries. Taking the mid-point of these estimates, the probability of dying from an occupational injury during a 40 year long career increases by a factor of $1.023^{40} \approx 2.5$.

Related literature. Mortality shocks have been introduced into frictional labor market models mainly to achieve a better fit to the data (Postel-Vinay and Robin, 2002). They are an important ingredient in quantitative OLG models such as Marchiori and Pierrard (2012), de la Croix et al. (2013), and Schuster (2021) to match the age and employment distribution in the population. In any of these occurrences, the risk of dying is treated as exogenous. However, deaths typically are neither an unpredictable random event nor are they unpreventable.[3] Furthermore, none of these papers allows the mortality rate to differ between employment states, while there is ample empirical evidence of a causal effect of job loss on mortality (Eliason and Storrie, 2009; Sullivan and Von Wachter, 2009). Our paper provides a first effort to extend the search and matching literature for endogenous mortality of employed workers.

Health economists have long acknowledged the endogenous nature of death and that socioeconomic variables such as education, wealth, and earnings shape individual health behavior (Grossman, 1972, 2000; Dalgaard and Strulik, 2014). While these factors are interacting trough the labor market, most model-theoretic contributions focus only on labor supply. Labor demand is either perfectly elastic (Capatina, 2015; Galama and van Kippersluis, 2019; Strulik, 2022) or based on firms hiring on a competitive labor market (Frankovic and Kuhn, 2019). Two recent papers, Galama and van Kippersluis (2019) and Strulik (2022), explicitly consider work-related mortality. In these papers, individuals are rewarded for higher 'job-related health stress' by a higher wage. While the model presented in this paper gives rise to a similar gradient between mortality and wages at the individual level, this relationship derives from endogenous worker-firm negotiations. The resulting mortality rate balances worker and firm incentives as traditionally viewed in the literature on occupational health and safety (Pouliakas and Theodossiou, 2013). By contrast, the work-related mortality rate is fully determined by the worker

[3] For this reason, the British Medical Association has started to ban the term "accident" in submissions to *The BMJ* (Davis, 2001). We follow this appeal and instead refer to injuries.

in Galama and van Kippersluis (2019) and Strulik (2022).[4]

Workplace safety is an important non-wage amenity of a job that has been considered in the literature on compensating wage differentials and hedonic wages for many decades (Thaler and Rosen, 1976). However, only a few papers have studied non-wage job characteristics in a labor market with search frictions. Blau (1991), Bonhomme and Jolivet (2009), Sullivan and To (2014), Pinheiro and Visschers (2015), and Jarosch (2021) estimate job search models where the amenity of a job is drawn from an exogenous distribution. Endogenous provision of amenities has been discussed by Hwang et al. (1998), Lang and Majumdar (2004), Dey and Flinn (2005), Flabbi and Moro (2012), Hall and Mueller (2018), and Bobba et al. (2022). While some of these papers consider workplace safety among the provided amenities, none takes into account its consequences on life expectancy or mortality.[5]

The paper proceeds as follows. Section 2 solves the planner's problem for the socially optimal mortality rate in a frictionless labor market. Section 3 introduces the search frictions and solves the planner's problem in the frictional labor market, before turning to the decentralized economy in Section 4. In Section 5, the main testable model prediction is verified using data on fatal occupational injuries from the US. Section 6 concludes. All mathematical proofs, model extensions, and robustness checks are delegated to the appendix.

2 Frictionless labor market

2.1 Demography and production

To assess the impact of search frictions on mortality, we first solve the social planner's problem in a frictionless labor market. Each period, the planner can freely allocate the mass N of living individuals to employment or unemployment. The mass of employed and unemployed is denoted by L and U, respectively. While unemployed die at an exogenous rate $m_U \geq 0$, the mortality rate of employed, m, is endogenously chosen by the planner. Assuming an exogenous mass of newborns $B > 0$, the population size evolves according to[6]

$$\dot{N} = B - mL - m_U U. \tag{1}$$

Every unemployed generates a flow of home production of $z > 0$. The production of an employed individual is measured in terms of the flow of effective output $y(m)$, which captures output minus the costs of safety measures. These costs can be direct, like regular maintenance of machines or purchasing of safety equipment, as well as indirect through lower productivity due to shorter work shifts or time spent on safety routines. The properties of the effective

[4]While Strulik (2022) allows one component of mortality to vary across occupations, this part is exogenous.

[5]Dey and Flinn (2005) assume that the provision of health insurance reduces the likelihood of a negative productivity shock due to deteriorating health. This leads to higher separation rates for uncovered workers from their current job, without adversely affecting their future health or reducing their (infinite) lifespan.

[6]We generally omit time indices to simplify notation. We do not model individual mortality as a state variable in order to keep the model tractable.

output function are summarized in Assumption 1.[7]

Assumption 1. *For $m \geq 0$, effective output $y(m)$ is twice continuously differentiable and satisfies*

(i) monotonicity and concavity, $y'(m) > 0$, $y''(m) < 0$, with $\lim_{m \to \infty} y'(m) = 0$,

(ii) for some $m > 0$, individuals produce more on a job than at home in present discounted value terms, $\frac{y(m)}{r+m} > \frac{z}{r+m_U}$,

(iii) but this is not the case at $m = 0$, $\frac{y(0)}{r} \leq \frac{z}{r+m_U}$.

By property (i), the current effective output of an employment relation can be increased by allowing higher mortality because this reduces prevention costs. Concavity implies that these output gains become smaller with increasing mortality. Equivalently, reducing mortality becomes more and more costly the lower it already is. This reflects that an initial drop in mortality can be achieved by relatively cheap measures such as hard hats, while further reductions in mortality require increasingly expensive measures.[8]

Properties (ii) and (iii) are technical. Essentially, property (ii) guarantees that employment is positive in optimum. Property (iii) ensures that the optimal mortality rate of employed individuals is strictly positive, as reducing the mortality rate to 0 would be too costly, making market production inferior to home production.

2.2 Social planner solution

Assuming that all agents have linear utility, the utilitarian planner's objective is to choose time paths of (m, U, L) that maximize the present discounted value of aggregate output,[9]

$$\int_0^\infty [y(m(t))L(t) + zU(t)]e^{-rt}\, dt,$$

subject to the aggregate population dynamics (1) as well as $L+U = N$ and $U \in [0, N]$. Ignoring the constraint on U for the moment and substituting $L = N-U$, the current value Hamiltonitian of the planner's problem reads

$$\mathcal{H} = y(m)(N - U) + zU + \nu[B - m(N - U) - m_U U],$$

[7] For simplicity, safety measures are assumed to have only a contemporaneous effect on mortality risk, which is therefore best interpreted as the risk of experiencing a fatal occupational injury (consistent with our empirical evidence in Section 5).

[8] Since our model is in continuous time, the worker is assumed to finish production $y(m(t))$ before he eventually dies with rate $m(t)$ at the next instant. In discrete time, depending on the duration of a period, a unimodal effective production function may be more realistic, as it allows to capture that the worker may die during the period t production process. In fact, all results of this paper continue to hold if Assumption 1(i) is replaced by the property that $y(m)$ attains a unique maximum at $\overline{m} > 0$ and that it is concave for $m < \overline{m}$.

[9] Besides maximizing agents' welfare, a planner could pursue additional goals, such as minimizing the number of deaths. Such considerations would naturally lead the planner's solution to differ from the decentralized equilibrium, which we therefore abstain from. We also abstract from individuals themselves having non-pecuniary costs of mortality. Extending the model in this direction is straightforward and does not alter our conclusions provided that the planner's valuation of a death coincides with the private valuation of a death, see Appendix A.1.

where ν is the costate to N.

Assuming $U < N$, the first order condition with respect to m is

$$\frac{\partial \mathcal{H}}{\partial m} = 0 \quad \Leftrightarrow \quad y'(m) = \nu. \tag{2}$$

By condition (2), the optimal mortality rate equates the marginal gain of mortality risk in terms of effective output, $y'(m)$, to the marginal cost of mortality risk, which equals the economic value of a life lost, ν. In an optimum, the latter variable evolves over time according to

$$\frac{\partial \mathcal{H}}{\partial N} = -\dot{\nu} + r\nu \quad \Leftrightarrow \quad \dot{\nu} = (r+m)\nu - y(m). \tag{3}$$

From this point onwards we focus on stationary solutions, $\dot{m} = 0$, which by (2) implies $\dot{\nu} = 0$ and reduces (3) to

$$\nu = \frac{y(m)}{r+m}. \tag{4}$$

Hence the steady state value of a life lost equals the present discounted value of foregone production. Combining this with (2), the optimal mortality rate solves

$$y'(m) = \frac{y(m)}{r+m}. \tag{5}$$

It is easy to see that at the optimal mortality rate, the value of a worker given in (4) is maximized. Proposition 1 establishes uniqueness of the planner's solution and verifies that the associated optimal level of unemployment is zero. Correspondingly, the population size is $N = L = \frac{B}{m}$ in steady state.[10]

Proposition 1. *Without search frictions, the social planner's problem has a unique stationary solution with $U^{**} = 0$ and mortality rate $m^{**} > 0$ characterized by* (5).

Condition (5) reveals that the socially optimal mortality rate m^{**} depends on the discount rate r as well as on the effective production function. The higher r, the less the planner values the future output gains relative to the current output costs of occupational safety, and the higher is the optimal mortality rate. To illustrate the dependence on the shape of the production function, assume $y(m) = Am^{\alpha}$ with $A > 0$ and $\alpha \in (0,1)$. It is easy to verify $m^{**} = \frac{\alpha}{1-\alpha}r$. Hence the tighter the link between mortality and effective output, the higher is the optimal mortality rate. For $\alpha \to 0$, a reduction in mortality has no detrimental effect on output and thus $m^{**} \to 0$. For $\alpha \to 1$, reducing mortality becomes increasingly costly and $m^{**} \to \infty$.[11].

[10] The prediction of full employment is due to our agents being *ex ante* homogeneous. If Assumption 1(ii) applied only to a fraction of the individuals (e.g. due to heterogeneity in z or m_U), the model would feature voluntary unemployment. While this is not the point of the paper, it is interesting to note from (5) that as long as the effective production function does not differ, any employed individual faces the same mortality rate.

[11] Note that the model does not take a stance whether the mortality of employed exceeds the mortality of unemployed. Depending on the parameterization, both outcomes can be achieved. Empirically, mortality rates of unemployed are higher than those of employed workers in most occupations (Eliason and Storrie, 2009; Sullivan and Von Wachter, 2009; Paglione et al., 2020).

3 Frictional labor market

3.1 Labor flows

From now on, assume that the labor market dynamics are subject to the search and matching frictions typical in the DMP framework. Each period, the mass of unemployed U and the mass of vacancies V are brought together by a constant returns to scale matching function $M(U,V)$. The rate at which vacancies are filled is denoted by $q(\theta) := \frac{M(U,V)}{V} = M(\frac{1}{\theta}, 1)$ where $\theta := \frac{V}{U}$ is the labor market tightness. The rate at which unemployed find a job is $p(\theta) := \frac{M(U,V)}{U} = q(\theta)\theta$, and the elasticity of the matching function with respect to unemployment is $\eta(\theta) := \frac{\partial \ln M(U,V)}{\partial \ln U} = -\frac{q'(\theta)\theta}{q(\theta)}$. These objects satisfy the standard properties of Assumption 2.

Assumption 2. *The job-finding rate $p(\theta)$ and the vacancy-filling rate $q(\theta)$ are continuously differentiable with*

(i) $\lim_{\theta \to 0} p(\theta) = 0$, $\lim_{\theta \to \infty} p(\theta) = \infty$, $p'(\theta) > 0$,

(ii) $\lim_{\theta \to 0} q(\theta) = \infty$, $\lim_{\theta \to \infty} q(\theta) = 0$, $q'(\theta) < 0$,

(iii) $\eta(\theta)$ *is non-decreasing.*

Everybody is assumed to participate in the labor market, such that $N = L + U$. The population dynamics are governed by the differential equations

$$\dot{L} = -(m+s)L + p(\theta)U, \tag{6}$$

$$\dot{U} = B + sL - (p(\theta) + m_U)U, \tag{7}$$

$$\dot{N} = B - mL - m_U U. \tag{8}$$

The dynamics of the aggregate population (8) are as above. The evolution of the mass of employed and unemployed are described by (6) and (7), respectively. Each period, unemployed find a job at rate $p(\theta)$, while employed move into unemployment at an exogenous rate $s > 0$. As before, employed individuals die at rate m, while unemployed individuals face an exogenous mortality rate m_U. Newborns start their economic lives without a job.

In a stationary economy with constant inflows, $\dot{B} = 0$, equations (6)–(8) yield

$$L = \frac{p(\theta)}{p(\theta)m + m_U(m+s)}B, \quad U = \frac{m+s}{p(\theta)m + m_U(m+s)}B, \quad N = \frac{m+s+p(\theta)}{p(\theta)m + m_U(m+s)}B.$$

The steady state unemployment rate is

$$u = \frac{U}{N} = \frac{m+s}{m+s+p(\theta)}. \tag{9}$$

3.2 Social planner solution

If the planner is not bound by the matching frictions and can freely move individuals between employment and unemployment, the analysis is as in Section 2.2. The typical assumption in the search and matching literature, however, is that the planner cannot overcome the frictions and must work through the matching function (Pissarides, 2000, Ch. 8). In contrast to Section 2, the planner then cannot control U and L directly but only indirectly via creating vacancies V. Assuming a flow cost $c > 0$ per vacancy, the planner maximizes

$$\int_0^\infty [y(m(t))L(t) + zU(t) - cV(t)]e^{-rt}\, dt$$

subject to the population dynamics (6)–(8) as well as $L + U = N$ and $U \in [0, N]$. While the planner essentially chooses time paths for (m, V), it is convenient to reformulate the problem in terms of (m, θ) by writing $V = \theta U$. Furthermore, we substitute $L = N - U$ and omit (6) as well as the static constraint on U from the maximization problem. The current value Hamiltonian then reads

$$\mathcal{H} = y(m)(N-U) + zU - c\theta U + \mu[B + s(N-U) - (p(\theta) + m_U)U] + \nu[B - m(N-U) - m_U U], \quad (10)$$

where μ and ν are the costates to U and N, respectively.

Assuming $0 < U < N$, the first order conditions for an interior optimum are

$$\frac{\partial \mathcal{H}}{\partial m} = 0 \quad \Leftrightarrow \quad y'(m) = \nu, \quad (11)$$

$$\frac{\partial \mathcal{H}}{\partial \theta} = 0 \quad \Leftrightarrow \quad c = -p'(\theta)\mu = -(1 - \eta(\theta))q(\theta)\mu. \quad (12)$$

Condition (11) coincides with (2), while condition (12) balances the costs of an additional vacancy with the benefits of lower unemployment through increased job-finding. In an optimum, the dynamics of the costate variables are

$$\frac{\partial \mathcal{H}}{\partial U} = -\dot{\mu} + r\mu \quad \Leftrightarrow \quad \dot{\mu} = (r + s + m_U + p(\theta))\mu + y(m) - z + c\theta - \nu(m - m_U), \quad (13)$$

$$\frac{\partial \mathcal{H}}{\partial N} = -\dot{\nu} + r\nu \quad \Leftrightarrow \quad \dot{\nu} = (r + m)\nu - y(m) - s\mu. \quad (14)$$

From this point onwards, we again focus on stationary solutions, $\dot{m} = \dot{\theta} = 0$. By the first order conditions, this implies $\dot{\nu} = \dot{\mu} = 0$. Equation (14) gives the economic value of a lost worker as

$$\nu = \frac{y(m) + s\mu}{r + m}. \quad (15)$$

Similar to (4), ν equals the present discounted value of a worker's forgone production in case of death. Yet, it now takes into account that the worker may have become unemployed in the future due to a separation shock. Combining (11) and (15) yields

$$y'(m) = \frac{y(m) + s\mu}{r + m}. \quad (16)$$

Comparing this condition to (5) reveals that while the search frictions do not affect the marginal gain of mortality risk, they lower its marginal costs, since unemployment reduces a worker's lifetime production in present discounted value terms (note that $\mu < 0$ by (12)). As a result, search frictions increase the optimal mortality rate, see Section 3.3 for further discussion.

Substituting (12) and (15) into (13) to replace c and ν, the steady state value of an additional unemployed becomes

$$\mu = -\frac{(r+m_U)y(m) - (r+m)z}{[r+m_U+p(\theta)\eta(\theta)](r+m) + s(r+m_U)}. \tag{17}$$

The value of μ corresponds to the change in the present discounted value of aggregate output if a worker switches from employment to unemployment. In optimum, this is negative by (12), such that frictional unemployment lowers aggregate output.

Substituting (17) back into (12) yields

$$(1-\eta(\theta))\frac{(r+m_U)y(m) - (r+m)z}{[r+m_U+p(\theta)\eta(\theta)](r+m) + s(r+m_U)} = \frac{c}{q(\theta)}. \tag{18}$$

Like in the basic DMP model, this equation determines optimal job creation. To pin down the optimal mortality rate, use (17) to eliminate μ from (16), which after some algebra yields

$$y'(m) = \frac{[r+m_U+p(\theta)\eta(\theta)]y(m) + sz}{[r+m_U+p(\theta)\eta(\theta)](r+m) + s(r+m_U)}. \tag{19}$$

With search frictions, a solution to the planner's problem satisfies (18)–(19).

As in the frictionless economy, it can be shown that the optimal mortality rate maximizes the value of a worker, ν, on the right-hand side of (19). Additionally, it turns out that the optimal level of mortality is such that the highest feasible labor market tightness θ is attained. In the frictional labor market, the planner therefore seeks to minimize the impact of the frictions on the job-finding rate $p(\theta)$. Consequently, the planner's solution corresponds to the unique peak of the job creation curve as postulated by Proposition 2.

Proposition 2. *With search frictions, the social planner's solution* (m^*, θ^*) *is unique and corresponds to the peak of the job creation curve* $\theta^*(m)$ *implicitly defined by* (18).

This result is graphically illustrated in Figure 1. JC corresponds to the job creation curve implicitly defined by (18). It is hump-shaped, which indicates that the planner creates fewer vacancies if the mortality of employed workers is very high (since the expected duration of matches is short) but also if mortality is very low (since the required safety measures depress effective output).[12] The job destruction curve JD is defined by (19) and downwards sloping. Intuitively, a higher tightness θ increases the job-finding rate and thus μ, as the expected output loss in case of unemployment decreases. By (15), this increases the valuation of a worker's life, ν, and thus the marginal cost of mortality risk. Therefore, the optimal mortality rate is decreasing in θ along the JD curve. The planner's optimum lies at the intersection of the two curves, which by Proposition 2 coincides with the peak of the JC curve.

[12]See Lemma 2 in the Appendix for a formal proof of the unimodality of $\theta^*(m)$.

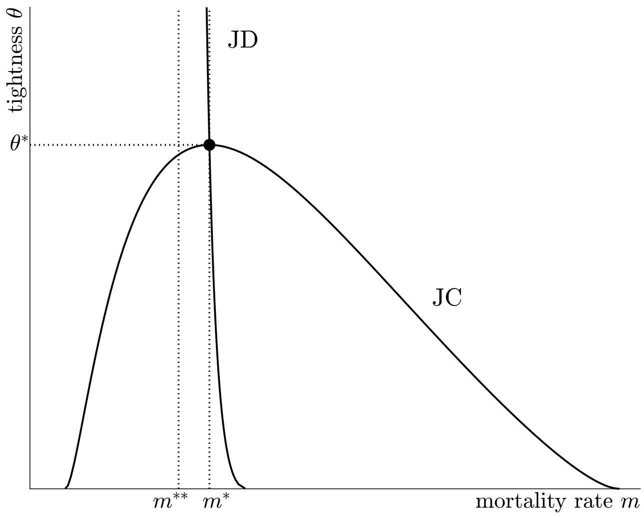

Figure 1. The Planner's solution (m^*, θ^*) in the presence of search frictions lies at the intersection of job creation curve JC and job destruction curve JD. m^{**} indicates the optimal mortality rate without search frictions.

3.3 The impact of search frictions on mortality

The difference in the optimality conditions for mortality (5) and (19) stems from the altered value of ν, which measures the value of a life lost in terms of foregone output. Since workers are more productive in jobs than at home ($\mu < 0$), the presence of frictional unemployment decreases a worker's expected lifetime production and thus decreases the marginal costs of mortality risk, compare (4) and (15). This implies that the optimal mortality rate is higher in the presence of labor market frictions. The result is robust to the introduction of non-pecuniary costs of death, which involve the planner in a trade-off between maximizing output and saving lives (see Appendix A.1). It also applies if agents are risk averse and the planner seeks to maximize aggregate welfare rather than aggregate output in the economy (see Appendix A.2).

The unambiguous increase in mortality was not to be expected, since *ceteris paribus*, a lower m could ameliorate frictional unemployment and reduce the expenditures for vacancy posting. However, Proposition 2 reveals that in the output-maximizing strategy, the planner directly addresses the ultimate source of the welfare losses, which is the depressed job-finding rate. It turns out that the job-finding rate depends on m only through the value of an employed worker and reaches its highest level when ν is maximized, which leads to condition (19).[13]

Proposition 3 demonstrates that the extent of excess mortality caused by the search frictions depends on the specific labor market conditions.

Proposition 3. *Let* $\phi := \frac{s}{r+m_U+p(\theta)\eta(\theta)}$. *The constrained efficient mortality rate* m^* *determined by* (19) *is strictly increasing in* ϕ. *For* $\phi \to 0$, *the frictionless mortality rate* m^{**} *given in* (5) *is attained.*

[13] This is evident from (12)–(14) implying $c = (1-\eta(\theta))q(\theta)\frac{(r+m_U)\nu - z}{r+m_U+p(\theta)\eta(\theta)}$.

It is straightforward to see from (19) that the optimal mortality rate depends on the labor market conditions only via the fraction given in Proposition 3. *Ceteris paribus*, the excess mortality caused by the frictions is higher, the higher the separation rate and the lower the job-finding rate or the less elastic the matching function responds to changes in unemployment.[14] With vanishing search frictions, $p(\theta) \to \infty$ for all θ, the fraction approaches zero, such that $m^* \to m^{**}$. The results of Proposition 3 are also evident from Figure 1. The job destruction curve JD approaches the vertical line $m = m^{**}$ for $\theta \to \infty$ and is located right of this line at any finite θ. The intersection with the JC curve therefore necessarily lies to the right of m^{**}, indicating excess mortality.

4 Decentralized frictional labor market

Having understood the planner's incentives with and without search frictions, we now decentralize the economy studied in the previous section. Mortality is no longer centrally mandated but bargained between firms and workers together with wages. Alternative determination schemes for occupational safety are considered in Appendix A.3.

4.1 Value functions

Each firm consists of one job that can either be filled or vacant. Assuming stationarity, the value of a filled and vacant job are, respectively,

$$rJ = y(m) - w - (s + m)(J - V),$$
$$rV = -c + q(\theta)(J - V).$$

A filled job generates a flow profit $y(m) - w$ and is destroyed by an exogenous separation at rate s and by death of the worker at rate m. A vacancy generates a flow cost c and is filled at rate $q(\theta)$. Assuming free market entry of firms, the value of a vacancy is zero in equlibrium, $V = 0$, which implies the free entry condition $J = \frac{c}{q(\theta)}$.

The value of employment and unemployment for the worker are, respectively,

$$rW = w - s(W - U) - mW,$$
$$rU = z + p(\theta)(W - U) - m_U U.$$

An employed worker consumes the wage w, moves to unemployment at rate s and dies at rate m. Unemployed consume their home production z, find a job at rate $p(\theta)$ and die at rate m_U.

[14]While exogenous in our model, the severity of search frictions may also change the mortality rate of unemployed m_U through their increased risk of long-term unemployment (Browning and Heinesen, 2012). Since the marginal cost of mortality risk on the right-hand side of (19) is decreasing in m_U, capturing this interaction would amplify the negative effect of search frictions on the provision of occupational safety. Intuitively, a worker's expected lifetime production then not only drops due to the presence of unemployment spells, but also because the mortality experienced while unemployed increases in the expected duration of these spells.

The value of death is zero, since the individual's consumption permanently drops to zero.[15]

4.2 Bargaining

Each period, firm and worker choose a wage w and a mortality rate m that jointly maximize the generalized Nash product $\Psi = (W-U)^{\gamma}(J-V)^{1-\gamma}$, where $\gamma \in (0,1)$ is the bargaining power of the worker.[16] From above, observe that $V=0$, $J = \frac{y(m)-w}{r+m+s}$, and $W = \frac{w+sU}{r+m+s}$. The value of unemployment U is an equilibrium object and taken as given in the bargaining process.

Assuming $W > U$ and $J > 0$, the first order conditions are

$$\frac{\partial \Psi}{\partial w} = 0 \quad \Leftrightarrow \quad \gamma J = (1-\gamma)(W-U), \tag{20}$$

$$\frac{\partial \Psi}{\partial m} = 0 \quad \Leftrightarrow \quad y'(m) = J + \frac{\gamma J}{(1-\gamma)(W-U)} W. \tag{21}$$

Condition (20) gives rise to the familiar Nash sharing rule, $W - U = \gamma S$ and $J = (1-\gamma)S$ where $S = J + W - U = \frac{y(m)-(r+m)U}{r+m+s}$ is the joint surplus of the match. Substituting this into (21) yields

$$y'(m) = J + W = \frac{y(m)+sU}{r+m+s}. \tag{22}$$

Similarly to the planner's conditions, the left-hand side of (22) measures the marginal benefit of mortality risk in terms of higher effective output. The right-hand side captures the marginal cost of mortality risk, which in the decentralized economy amounts to losing the joint value of the match, $J + W$. This value comprises the expected output generated on the current job, $\frac{y(m)}{r+m+s}$, and (via U) the worker's expected production in future jobs and during unemployment spells.

Notice that the bargaining outcome can be interpreted sequentially. First, a wage is negotiated by Nash Bargaining for any fixed m, which gives rise to a wage schedule $w(m) = \gamma y(m) + (1-\gamma)(r+m)U$. It is easy to see that this schedule is increasing and concave in m. The worker's reward for higher risk taking equals $w'(m) = \gamma y'(m) + (1-\gamma)U$ and combines a share γ of the additional effective output and a share $1-\gamma$ of the outside option lost in case of dying. In a second step, the mortality rate is determined. Since at any wage each party receives a fixed share of the joint surplus S, they agree to set m to maximize S.[17]

[15] In Appendix A.1 we consider additional non-pecuniary costs of death, which do not alter our main conclusions.

[16] The view that workers and firms bargain over a compensation package that includes non-wage components, has, for instance, been adopted in Dey and Flinn (2005), where the worker's coverage by health insurance is negotiated together with the wage. We study alternative determination schemes for wages and occupational safety in Appendix A.3.

[17] Formally, $\max_{(m,w)} (W-U)^{\gamma} J^{1-\gamma} = \max_m \left\{\max_w (W-U)^{\gamma} J^{1-\gamma}\right\} = \gamma^{\gamma}(1-\gamma)^{1-\gamma} \max_m S$. The first order condition of this maximization problem, $\frac{\partial S}{\partial m} = 0$, corresponds to (22).

4.3 Equilibrium

By the Nash sharing rule, the equilibrium value of unemployment satisfies $(r + m_U)U = z + p(\theta)\gamma S$. Substituting this into the definition of S gives equilibrium surplus

$$S = \frac{(r + m_U)y(m) - (r + m)z}{(r + m_U + p(\theta)\gamma)(r + m) + (r + m_U)s}. \tag{23}$$

The corresponding equilibrium value of unemployment is

$$U = \frac{p(\theta)\gamma y(m) + (r + m + s)z}{(r + m_U + p(\theta)\gamma)(r + m) + (r + m_U)s}. \tag{24}$$

Plugging (23) into the free entry condition, noting $J = (1 - \gamma)S$, yields

$$(1-\gamma)\frac{(r + m_U)y(m) - (r + m)z}{(r + m_U + p(\theta)\gamma)(r + m) + (r + m_U)s} = \frac{c}{q(\theta)}, \tag{25}$$

while substituting (24) into (22) gives, after some algebra,

$$y'(m) = \frac{(r + m_U + p(\theta)\gamma)y(m) + sz}{(r + m_U + p(\theta)\gamma)(r + m) + (r + m_U)s}. \tag{26}$$

A labor market equilibrium $(\hat{m}, \hat{\theta})$ is characterized by equations (25)–(26). Similar to the planner's solution in Section 3.2, it can be verified that the labor market equilibrium corresponds to the peak of the job creation curve, which is now implicitly defined by (25). The reason is that the Nash bargaining implies that m maximizes joint surplus S, which by the free entry condition is equivalent to maximizing θ.

Proposition 4. *The equilibrium $(\hat{m}, \hat{\theta})$ is unique and corresponds to the peak of the job creation curve $\hat{\theta}(m)$ implicitly defined by* (25)*.*

Thus, the equilibrium looks qualitatively identical to the planner's solution in Figure 1.

4.4 The impact of search frictions and externalities on equilibrium mortality

It is straightforward to proof the following equivalent of Proposition 3 in the decentralized economy.

Proposition 5. *Let $\psi := \frac{s}{r+m_U+p(\theta)\gamma}$. The equilibrium mortality rate $\hat{m}$ determined by* (26) *is strictly increasing in ψ. For $\psi \to 0$, the frictionless mortality rate m^{**} given in* (5) *is attained.*

Therefore, the mortality rate of the decentralized economy with frictions necessarily lies above the optimal mortality rate of the frictionless economy. It remains to determine, however, how it relates to the mortality rate that a constrained planner would choose.

The labor market equilibrium may differ from the planner's solution (m^*, θ^*) due to two externalities that are present in the model. The classical matching externalities may lead the equilibrium tightness to deviate from θ^* (Pissarides, 2000, Ch. 8). This is because an individual firm does not take into account that opening an additional vacancy lowers the vacancy-filling rate of all firms, while on the workers' side, an additional job seeker reduces the job-finding rate for all other job seekers. Additionally, our model features an externality that directly affects the mortality rate. As safety measures are bilaterally negotiated between a firm and a worker, the fact that a worker's death not only terminates the current employment relation but lowers aggregate labor supply is in general not taken into account.

4.4.1 The labor supply externality

The fact that a deceased worker reduces aggregate labor supply is internalized in the firm-level negotiations if the private costs of mortality equal the social costs of mortality. In this case, conditions (16) and (22) coincide, which proofs equivalent to

$$U = \frac{y(m) + (r + m + s)\mu(m, \theta)}{r + m} \tag{27}$$

where $\mu(m, \theta)$ is the shadow price that a planner assigns to an additional unemployed for a given pair (m, θ). This shadow price can be obtained from (13)–(14) and equals

$$\mu(m, \theta) = -\frac{(r + m_U)y(m) - (r + m)(z - c\theta)}{(r + m_U + p(\theta))(r + m) + s(r + m_U)}. \tag{28}$$

Next, note that free entry and Nash bargaining imply $c\theta = \theta q(\theta)(1-\gamma)S = (1-\gamma)p(\theta)\frac{y-(r+m)U}{r+m+s}$. Substituting this into (28) and plugging the resulting expression into (27) after some algebra yields (24). This proofs that the labor supply externality is internalized in the labor market equilibrium. Even though private agents do not explicitly take into account that a dead worker reduces labor supply on aggregate, in equilibrium this is accurately reflected in the outside option that the worker considers in bargaining.

The observation that the labor supply externality is internalized in equilibrium hinges on a particular property of the bargaining scheme proposed in Section 4.2. As mentioned there, the negotiated mortality rate maximizes the *joint* surplus of firm and worker. This is essential, since the production potential outside the firm is only taken into account by the worker, but not by the firm. In Appendix A.3 we investigate alternative schemes to determine occupational safety, and their ability to internalize the labor supply externality.

4.4.2 Matching externalities

Even though the labor supply externality is internalized in equilibrium, the mortality rate $\hat{m}$ may differ from the constrained planner's optimal m^*. Externalities that arise from the matching process affect the equilibrium value of U given in (22) and therefore the mortality rate. Indeed, we observe that the equilibrium conditions (25)–(26) coincide with the planner's conditions (18)–(19) if and only if $\gamma = \eta(\theta)$. This means that the worker's bargaining power in the negotiation equals the elasticity of the matching function with respect to unemployment, and corresponds to the familiar Hosios (1990) condition. In this case, the labor market equilibrium is constrained

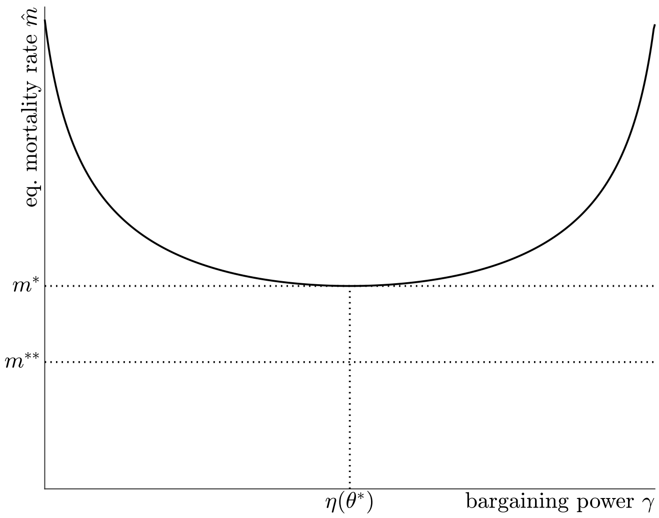

Figure 2. Equilibrium mortality rate $\hat{m}$ as a function of γ. m^* and m^{**} denote the planner's optimal mortality rate with and without search frictions, respectively.

efficient and attains the mortality rate m^*. Proposition 6 states that *any* deviation from the Hosios condition increases the mortality rate above its constrained efficient level. Hence both a too low and a too high bargaining power of workers strengthens the negative effects of search frictions on occupational safety.

Proposition 6. *The equilibrium attains the constrained efficient mortality rate m^* if and only if $\gamma = \eta(\theta^*)$. Otherwise, the equilibrium mortality rate exceeds m^*.*

The result of Proposition 6 is illustrated in Figure 2. The relation between bargaining power and equilibrium mortality is U-shaped. While it seems intuitive that workers with little bargaining power (and correspondingly small wage) are willing to take more risk to raise their income, observing the same behavior for workers with high bargaining power is perhaps surprising. It arises from the fact that their high wage reduces their job-finding rate, which reinforces the search frictions and increases the negotiated mortality level. Technically, the equilibrium mortality rate is inversely related to the equilibrium value of unemployment U by (22). Lemma 3 in the appendix shows that U attains its highest value for $\gamma = \eta(\theta^*)$, such that mortality achieves its minimum at this point, where it equals the constrained efficient rate m^*.[18] Even if all externalities can be internalized, the mortality rate is still higher than in a frictionless labor market, where it equals m^{**}. While appropriately designed policies can reduce mortality below m^*, this comes with a loss in aggregate output as discussed in the next section.

[18]The property that the equilibrium value of unemployment is maximized under the Hosios condition is inherited from the basic DMP model, see Pissarides (2000, p.187). Endogenous mortality does not destroy this property since $\frac{\partial U}{\partial m} = \frac{\partial S}{\partial m} = 0$ for any given γ.

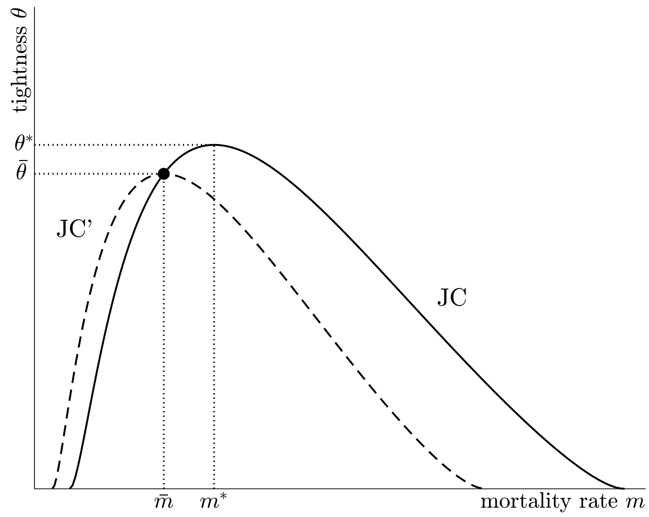

Figure 3. The government's desired combination $(\bar{m}, \bar{\theta})$ lies on the planner's job-creation curve JC. It is implemented as labor market equilibrium by any policy that entails a job creation curve that peaks at this point, for example JC'.

4.5 Policy

Suppose that there is a government who seeks to maximize aggregate output but is not willing to accept a mortality rate higher than some pre-specified level $\bar{m}$. Hence, the government solves the planner's problem from Section 3.2 subject to the additional constraint $m \leq \bar{m}$, and tries to establish the resulting optimum as a decentralized equilibrium.

We can distinguish two cases. For $\bar{m} \geq m^*$, the government's optimum corresponds to the planner's solution (m^*, θ^*) from Section 3.2 since the constraint on mortality does not bind. By Proposition 6, this optimum is attained as equilibrium if the Hosios condition is satisfied, such that the government should focus on establishing the right bargaining weights.

For $\bar{m} < m^*$, we know from the analysis of Section 3.2 that the optimal mortality rate equals $\bar{m}$ since this choice leads to the highest labor market tightness. The solution to the government's problem $(\bar{m}, \bar{\theta})$ then lies on the planner's job creation curve (18) illustrated by the solid line in Figure 3. To implement this point as an equilibrium, the government must alter the job creation curve of the decentralized economy (25) such that it peaks at this point, compare Proposition 4.[19] The dashed line JC' indicates one possible job creation curve that the government could implement to this purpose, but it is evident that inifinitely many possibilities exist. We shall refer to any policy that decentralizes $(\bar{m}, \bar{\theta})$ as an equilibrium as an *optimal policy* and provide two specific examples in Appendix A.4.

All policies that implement $\bar{m} < m^*$ have in common that while they reduce mortality, this comes at the cost of lower aggregate output, which is maximized in the constrained planner's optimum (m^*, θ^*). The output loss stems from two sources: First, effective output $y(m)$ in all matches is reduced by the additional safety measures and second, less matches are created

[19]If the Hosios condition is satisfied for all θ, i.e. $\eta(\theta) \equiv \gamma$, the job creation curve of the decentralized economy without policy equals the planner's job creation curve JC.

as firms post fewer vacancies. The observation that the planner's job creation curve is flat at m^* suggests that if an optimal policy is used and $\bar{m}$ is close to m^*, the equilibrium effect on job creation does not need to be taken into account when evaluating the aggregate output loss resulting from the policy. This is formally proved in in the following proposition.

Proposition 7. *Let $r \to 0$. Then using an optimal policy to implement mortality rate $\bar{m} < m^*$ changes aggregate output by $\frac{y''(m^*)}{2} L(\bar{m} - m^*)^2 + \mathcal{O}(\bar{m}^3) < 0$.*

Proposition 7 states that up to second order, the output loss from an optimal policy depends only on the cumulated additional marginal costs of safety measures. These are determinated by the curvature of the effective output function, $y''(m^*)$, the deviation from the planner's solution, $\bar{m} - m^*$, as well as the mass of workers, L.[20]

5 Empirical assessment

The last section of the paper confronts the model with data on occupational mortality. The main testable model prediction is provided by Proposition 5. It claims that the equilibrium mortality rate of workers rises in response to a *ceteris paribus* increase in $\psi = \frac{s}{r+m_U+p(\theta)\gamma}$. We show below that this expression is strongly tied to the equilibrium unemployment rate $\hat{u}$. Our measure of mortality will be the incidence of a fatal occupational injuries in the US. We do not consider occupational diseases as they can involve substantial lags between exposure, outbreak, and death. Additionally, there is substantial uncertainty about the extent to which a fatal disease can be attributed to work-related factors.[21]

Previous empirical work has focused on fluctuations in occupational injuries over the business cycle. This was motivated by the early observation that the number of reported injuries tends to go down in a recession (Kossoris, 1938). Boone and van Ours (2006) and Boone et al. (2011) find that this is due to changes in workers' reporting behavior rather than a change in the incidence of work-related injuries *per se*. Workers fear that an accident at work may increase their chance of being laid off later on, which is particularly detrimental when alternative jobs are scarce. As a consequence, they tend to hide minor injuries from the employer in a recession. Clearly, the issue of selective reporting does not apply to fatal occupational injuries, whose incidence rate Boone and van Ours (2006) and Leombruni et al. (2019) find to be unaffected by the business cycle.

While labor market conditions vary over the business cycle, Proposition 5 cannot easily be tested using variation over time. A classical business cycle shock is a shock to worker productivity and thus the production function $y(m)$. The labor market is only affected indirectly through induced changes in firms' hiring and firing. Proposition 5 instead concerns *ceteris paribus* variations in labor market conditions, for instance through variations in the separation

[20]The coefficient on the cubic term in the expansion is $\frac{y'''(m^*)}{6} L + \frac{y''(m^*)}{2} \frac{dL}{dm}\Big|_{m^*}$ and thus also captures the equilibrium effect on employment. Because $\frac{dL}{dm} < 0$ at $m = m^*$, this poses in an additional negative effect on output for $\bar{m} < m^*$.

[21]For instance, an observed death from lung cancer could originate from exposure to hazardous substances at work, but also from air pollution outside the workplace or smoking.

rate or the efficiency of the matching process.[22] We therefore exploit variation across different labor markets (US states) to test our hypothesis.

5.1 Data

We combine data from two sources. The Census of Fatal Occupational Injuries (CFOI) collects information on all fatal work-related injuries in the US. It has been initiated in 1992 and is administered by the Bureau of Labor Statistics (BLS). We use the latest public use file available from the BLS website, which contains information from 2011 onwards.[23] It allows to disaggregate the number of fatal injuries by year, US state, two-digit occupation code, and age group. Since occupational deaths are a relatively rare event but may spike in certain years, we aggregate all deaths over the years 2011–2018. We do not consider more recent years due to a change in the occupational classification used in the CFOI. The resulting state-occupation-age cells are the primary units in our econometric analysis.[24] We restrict ourselves to individuals between age 20 and 65 to reduce selection effects. Our final sample consists of 5,610 state-occupation-age cells ($51 \times 22 \times 5$), of which 2,353 feature at least one occupational injury in the considered time frame.[25]

Since the CFOI does not include information on employment in these cells, we obtain this and additional demographic information from the Current Population Survey (CPS), using the monthly records from January 2011 to December 2018.[26] Because the location of an individual's workplace is not surveyed, we assume that individuals work in the state where their household is situated. In each cell, we compute the average number of hours worked per week to determine workers' actual exposure to occupational mortality risk and deduce the number of full-time equivalent workers. Additionally, we compile information relating to the distribution of sex, race, ethnicity, exact age, type of work, and unionization of workers at the cell-level. All these characteristics have previously been associated with differences in occupational mortality (Loomis and Richardson, 1998; Pegula, 2004; Orrenius and Zavodny, 2009; Morantz, 2013; Smith and Pegula, 2020). We also obtain the share of workers with high-school and college degrees. To measure labor market conditions, we additionally require information on unemployment in each cell. While age and state are straightforward to observe for unemployed, their occupational assignment is less clear. If an individual reports being unemployed, the CPS documents the occupation of the individual's last job. However, we observe that more than half of the unemployed who take up a new job switch to a different two-digit occupation. Therefore,

[22] The empirical evidence on acyclical occupational mortality is in line with our model. As search frictions vanish, we have seen on page 6 that a change in the worker productivity A does not affect m^{**}. In the frictional setting, an increase in A leads to opposing effects on the equilibrium mortality rate. The higher A tends to increase m^*, while the equilibrium effect through higher vacancy posting tends to decrease m^*.

[23] Downloaded on June 17, 2022 from `https://download.bls.gov/pub/time.series/fw/`.

[24] A second reason for pooling across years is the need to match the number of deaths with survey information on employment, for which in a given state-occupation-age cell no respondents may exist in some years.

[25] The 51 states include the District of Columbia. The occupation groups are the 22 two-digit occupations of the SOC 2010, excluding military specific occupations, which are not covered by the CPS. The 5 age groups are 20-24 years, 25-34 years, 35-44 years, 45-54 years, 55-64 years.

[26] We used the public microdata files provided by the IPUMS project (Flood et al., 2021), downloaded on Oct. 12, 2022.

the CPS reported number of unemployed in a given state-occupation-age cell may differ from the actual number of job seekers in this cell. Since we lack information about which jobs unemployed look for, we assign them to their last occupation and return to this issue in one of our robustness checks. Detailed summary statistics on all variables used in the empirical analysis are given in Table D1 in Appendix D.

5.2 Empirical strategy

Our estimation exploits the regional variation of unemployment and fatal occupational injuries across US states to identify the link between labor market conditions and occupational mortality rates. We fit a range of count data regression models with the discrete dependent variable D_{ais} measuring the number of fatal occupational injuries in age group a, occupation i, and state s. We assume this random variable to have conditional mean

$$\mathbb{E}[D_{ais}|\mathcal{X}_{ais}] = \mu_{ais} N_{ais}, \tag{29}$$

where N_{ais} is employment in the respective cell measured in full-time equivalents. The mortality rate μ_{ais} is assumed to be of exponential form,

$$\mu_{ais} = \exp(\alpha_{ai} + \beta_s + \zeta u_{ais} + \delta X_{ais}), \tag{30}$$

where α_{ai} are age-occupation fixed effects, β_s are state fixed effects, and u_{ais} is the unemployment rate in the respective cell. The matrix X_{ais} contains additional cell-specific characteristics described below.

Our main coefficient of interest is ζ, which measures the semi-elasticity of the unemployment rate on the mortality rate from occupational injuries. Our model suggests that the effect of labor market conditions on the occupational mortality rate can be identified by variations in the unemployment rate. To see this, note that according to Proposition 5, the equilibrium mortality rate $\hat{m}$ depends on the labor market conditions only via $\psi = \frac{s}{r+m_U+p(\hat{\theta})\gamma}$. Since interest rate and mortality rates are small relative to the labor market flows, $\psi \approx \frac{s}{p(\hat{\theta})\gamma}$. Using the same argument, the steady state unemployment rate (9) can be approximated as $\hat{u} \approx \frac{s}{s+p(\hat{\theta})}$. Combining both expressions reveals $\psi \approx \frac{\hat{u}(1-\hat{u})}{\gamma}$, such that the mortality rate depends on the labor market conditions via the unemployment rate and the bargaining power. For our main results, the cell-specific unemployment rate are constructed from CPS data as described above. Alternative definitions and measures relating to unemployment are considered as robustness checks. Since the bargaining power cannot be observed directly, we assume it to be captured by the fixed effects.[27]

[27] We also include the share of workers covered by a union contract among the controls X_{ais}. This is an imperfect proxy for bargaining power, however, as unions affect mortality not just indirectly through their impact on wages, but also directly through promoting workplace safety. Hirsch et al. (1997), for instance, suggest that unions assist their members in filing compensation claims, which increases employer's anticipated costs from occupational injuries and fosters investment into safety measures. Our estimation results do not show a statistically significant impact of unions after controlling for fixed effects.

	dependent variable: number of occupational fatalities			
	Poisson	*NB2*	*Poisson*	*NB2*
	(1)	(2)	(3)	(4)
unemployment rate	1.470***	2.269***	2.222***	2.603***
	(0.606)	(0.688)	(0.697)	(0.621)
age group × occupation FE	✓	✓	✓	✓
state FE	✓	✓	✓	✓
demographic characteristics			✓	✓
observations	5,609	5,609	5,606	5,606
overdispersion	0.048***	0.300***	0.044***	0.262***

Poisson and Negative Binomial (NB2) regressions on state-occupation-age group cells with the number of occupational fatalities as dependent variable and full-time equivalents as exposure variable. Demographic characteristics include share of male workers, share of white, black and Asian non-hispanic workers, share of hispanic workers, share of high-school and college graduates, share of workers covered by a union contract, mean age, and a quadratic polynomial in mean hours worked. For Poisson, *overdispersion* reports the coefficient estimate of α in the OLS regression $Var(D|\mathcal{X}) = \mathbb{E}(D|\mathcal{X}) + \alpha[\mathbb{E}(D|\mathcal{X})]^2 + \varepsilon$ using Poisson fitted values, see Cameron and Trivedi (1990). For NB2, *overdispersion* gives the MLE of α based on a Negative Binomial distribution for $D|\mathcal{X}$. In both cases, significant deviations from 0 indicate inadequacy of the Poisson model. Standard errors are clustered at the state level. Coefficient significance levels: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 1. Effect of unemployment on mortality from occupational injuries

Our specification (30) includes a full set of age × occupation dummies, which implies that the coefficient vector is identified from variation across states s. This is crucial to verify our theory, since different age groups and different occupations are likely to exhibit different productivities and different marginal costs of safety provision, leading to different effective production functions $y_{ai}(m)$. In fact, equation (5) reveals that theoretically, any observed variation in mortality rates could be explained by different effective production functions alone. Our identification of the effect of labor market conditions (ζ) is therefore based on the assumption that for given age group and occupation, the effective production function is the same in all states. Since this is possibly too restrictive, we include state fixed effects in (30) to capture unobserved regional heterogeneity that affects all age groups and occupations alike. In a robustness check, we interact state and occupation fixed effects to control for unobserved regional differences within occupation.

5.3 Results

Table 1 presents our main estimation results based on equations (29)–(30) using Poisson and Negative Binomial (NB2) regressions. While coefficient estimates are obtained by maximum likelihood, inference is based on clustered standard errors robust to deviations from the postulated distributions and possible error correlation within states.[28] Columns (1) and (2) report our baseline estimates, controlling just for the unemployment rate and fixed effects. Both the Poisson and the NB2 regression yield a positive and statistically significant marginal effect of unemployment. The regression-based test of Cameron and Trivedi (1990) strongly rejects the Poisson assumption that the conditional variance of the data equals its conditional mean, indicating overdispersion. The NB2 regression results are therefore our preferred ones and state that a 1 percentage point higher unemployment rate is associated with a 2.3% higher incidence of fatal occupational injuries per full-time worker. This effect is also significant in economic terms, since experiencing a 1 percentage point higher unemployment rate throughout a 40 year long career increases the probability of dying from a fatal injury by a factor of $1.023^{40} \approx 2.5$.

The regressions in columns (3) and (4) additionally control for a range of demographic characteristics. These include the cell-specific shares of male workers, white, black and Asian non-hispanic workers, hispanic workers, unionized workers, and self-employed workers. Additionally, we include the share of workers with high school and college degrees to addresses potential unobserved heterogeneity in worker abilities that affect occupational mortality and the incidence of unemployment in the same way. Since occupational fatality rates are strongly correlated with age (Smith and Pegula, 2020), we also control for the mean age within a cell to reduce potential omitted variable bias arising from our discretization of age.[29] Additionally, we include a quadratic polynomial in the average usual hours worked, since Folkard and Lombardi (2006) and Fischer et al. (2017) suggest a possibly nonlinear relationship between working hours and mortality risk. Compared to the baseline estimates, the inclusion of demographic covariates increases the marginal effect of unemployment. While the difference in the Poisson and NB2 estimates reduces, the Poisson assumption is still rejected. The full regression table is shown in Table D2.

Alternative measures. Although our model suggests that the occupational mortality rate is affected by labor market conditions via the unemployment rate, alternative measures can be considered. The CPS data allows to compute indicators relating to the equilibrium probability of job-finding, $p(\hat{\theta})$. While the number of observations within each cell is not sufficient to construct job-finding rates from observed transitions, the CPS inquires the duration of unemployment. From this information we compute the mean duration of unemployment as well as the share of long-term unemployed in a cell, which we define as unemployment that lasts for at least 52 weeks. Negative Binomial regressions using these two measures are shown in Table 2. The results corroborate our main findings. A 1 month higher average duration of unemployment is associated with a 1.3% higher mortality rate, while a 10 percentage point higher share of long-term unemployed is associated with a 2.5% higher mortality rate.

[28]The maximum likelihood (ML) estimates of the Poisson and the NB2 model are consistent provided that the conditional mean function is correctly specified, even if the assumed probability distribution is wrong. In the latter case, however, the ML standard errors are not correct and robust alternatives should be used. See Chapter 3 in Cameron and Trivedi (2013) for further details.

[29]We refrain from including tenure as an additional control for unobserved ability as it highly correlates with age and is only inquired biennially.

	dependent variable: number of occupational fatalities			
	(1)	(2)	(3)	(4)
mean months in unemp.	0.013**	0.014**		
	(0.006)	(0.006)		
share of long-term unemp.			0.252**	0.267**
			(0.117)	(0.123)
age group × occupation FE	✓	✓	✓	✓
state FE	✓	✓	✓	✓
demographic characteristics		✓		✓
observations	5,515	5,512	5,515	5,512
overdispersion	0.301***	0.264***	0.301***	0.264***

Negative Binomial (NB2) regressions on state-occupation-age group cells with the number of occupational fatalities as dependent variable and full-time equivalents as exposure variable. Demographic characteristics include share of male workers, share of white, black and Asian non-hispanic workers, share of hispanic workers, share of high-school and college graduates, share of workers covered by a union contract, mean age, and a quadratic polynomial in mean hours worked. Overdispersion gives the MLE of α in $Var(D|\mathcal{X}) = \mathbb{E}(D|\mathcal{X}) + \alpha[\mathbb{E}(D|\mathcal{X})]^2$ based on a Negative Binomial distribution for $D|\mathcal{X}$. Standard errors are clustered at the state level. Coefficient significance levels: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 2. Effect of search duration on mortality from occupational injuries

Robustness checks. We perform a series of robustness checks that account for several imperfections of the CFOI and CPS data. Since none of them alters our main conclusions, we only present the essentials at this point and refer the interested reader to Appendix C for further details. First, we check whether our results are driven by self-employed, which we are included in our data but are not captured in the model. To this purpose, we add an interaction term between unemployment and the share of self-employment, which turns out to be not significant. Second, we rule out that our results are driven by omitted variable bias relating to regional characteristics that go beyond the state fixed effects. In particular, we include industry shares among the covariates to capture regional differences in the distribution of occupations across industries. We additionally interact state fixed effects with occupation fixed effects to control for unobserved regional differences within occupations. The results remain close to our main regressions. Third, we address the issue that our definition of the unemployment rate used above does not take into account that unemployed workers frequently search for a new job in an occupation that differs from their previous one. To this purpose, we construct an adjusted unemployment rate based on realized transitions between occupations. Again, the results hardly differ from our main regressions. Fourth, we acknowledge that variables computed from the CPS may exhibit substantial uncertainty in some cells due to a few respondents. To show robustness of our main results, in a first check we exclude a quarter of the cells for which have the least number of underlying individual observations. In a second check, we resort to the much larger American Community Survey (ACS) which allows to construct most of the variables that enter our main regression. Both exercises have little impact on the marginal effect of unemployment, although standard errors increase. The coefficient estimates are nevertheless significant at the 5% level.

6 Conclusion

This paper studied the provision of occupational safety in a labor market with search frictions. To this purpose, the basic Diamond-Mortensen-Pissarides model was extended for mortality shocks with endogenous arrival rate. The presence of search frictions was found to increase the socially optimal mortality rate by lowering safety levels. While the marginal costs of safety measures are unaffected by the frictions, periods of involuntary unemployment decrease a worker's expected lifetime production and utility, and hence the long-run gains of safety measures. In a decentralized setting, externalities related to matching and bargaining may lead to a further increase in mortality. Exploring a wide scope of determination schemes for wages and occupational safety, we found that the negotiating parties generally internalize the labor supply externality, i.e. the effect of a higher mortality rate on aggregate labor supply. This is far from obvious, since none of the parties explicitly takes the aggregate effects of their decisions into account. Yet, in equilibrium, the worker's outside option turns out to reflect the correct "price" of mortality risk. The matching externalities are internalized if and only if the Hosios (1990) is satisfied. Any deviation from the Hosios condition leads to higher mortality due to a further drop in workers' expected lifetime production.

Many recent policy initiatives aim to increase occupational safety. This can be welfare improving if the social costs of work-related injuries and diseases exceed the costs considered by private agents. In our model, the only distortions of private incentives were due to labor supply and matching externalities, which can be avoided by giving workers an appropriate bargaining weight in firm-level negotiations. In practice, additional factors such as asymmetric information, cognitive biases, and other externalities may further distort the private provision of occupational safety (Pouliakas and Theodossiou, 2013). While policies that focus primarily on occupational safety seem suitable to correct these distortions, they are less suited to address the excessive mortality caused by the search frictions. As we demonstrated, once all externalities have been internalized, a further reduction in mortality inevitably lowers aggregate output and welfare. To ameliorate the detrimental mortality effects of search frictions, these must be tackled more directly. Accelerating the matching of unemployed to job openings, for example, could at the same time increase equilibrium safety levels and aggregate output. Along these lines, a potential rise in long-term unemployment driven by increased automation may inhibit the success of policy initiatives to boost occupational safety for a part of the labor force.[30]

The model analyzed in this paper was purposefully kept simple to identify the main mechanisms that affect the provision of occupational safety in a labor market with search frictions. We believe that these mechanisms will remain of central importance in more complex versions

[30] Compare Pissarides (2020), Schmidpeter and Winter-Ebmer (2021), and Cords and Prettner (2022).

of the model. Indeed, our model is general enough to be extended in many directions. For instance, premature death of a worker is the most extreme implication of low occupational safety. Many adverse economic effects already occur during the worker's lifetime in the form of chronic diseases or permanent disability.[31] In modern welfare states, a big chunk of health expenditures are born by the public and are thus not reflected in private decision-making. This creates an externality absent in the presented model. Furthermore, we abstracted from modeling education, which ultimately determines the characteristics of an individual's potential jobs. Distortions in the provision of occupational safety are likely to distort schooling decisions and occupational choices as well. We also neglected life-cycle features. Individual attitudes towards health hazards may change over a worker's lifetime depending on age, health, and socioeconomic factors. This may call for policies targeted at particular subpopulations. These and further questions are left for future research.

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A Model extensions

A.1 Non-pecuniary costs of death

Besides maximizing aggregate output, a utilitarian planner may also seek to minimize the death toll. Assuming that the planner values each death (irrespective of being work-related or not) at $\Lambda \geq 0$ units of output, the objective function becomes

$$\int_0^\infty [y(m(t))L(t) + zU(t) - cV(t)]e^{-rt}\,dt - \Lambda \int_0^\infty [m(t)L(t) + m_U U(t)]e^{-rt}\,dt,$$

where $V(t) \equiv 0$ in the absence of search frictions. Taking the same steps as in Section 2 and Section 3, the optimal mortality rate is characterized by $y'(m) = \frac{y(m)+r\Lambda}{r+m}$ in the economy without frictions and as

$$y'(m) = \frac{[r + m_U + p(\theta)\eta(\theta)][y(m) + r\Lambda] + s[z + r\Lambda]}{[r + m_U + p(\theta)\eta(\theta)](r + m) + s(r + m_U)},$$

$$(1 - \eta(\theta))\frac{(r + m_U)[y(m) + r\Lambda] - (r + m)[z + r\Lambda]}{[r + m_U + p(\theta)\eta(\theta)](r + m) + s(r + m_U)} = \frac{c}{q(\theta)}$$

in the frictional case. These expressions coincide with equations (5), (18), (19) except that the flow production of employed and unemployed individuals is increased by $r\Lambda$. In both the frictionless and the frictional setting, an increase in Λ increases the marginal benefit of safety measures and hence reduces the optimal m. For any given Λ, mortality is higher in the economy with search frictions as Proposition 3 continues to hold.

Introducing non-pecuniary costs of death in the decentralized economy changes the value functions of the worker to

$$rW = w - s(W - U) - mW - mD,$$
$$rU = z + p(\theta)(W - U) - m_U U - m_U D,$$

where $D \geq 0$ is the disutility a worker attaches to her own death. The equilibrium is characterized by

$$y'(m) = \frac{[r + m_U + p(\theta)\gamma][y(m) + rD] + s[z + rD]}{[r + m_U + p(\theta)\gamma](r + m) + s(r + m_U)},$$

$$(1 - \gamma)\frac{(r + m_U)[y(m) + rD] - (r + m)[z + rD]}{[r + m_U + p(\theta)\gamma](r + m) + s(r + m_U)} = \frac{c}{q(\theta)}.$$

Similar to above, a higher D increases the flow production values of a worker and hence the marginal benefit of safety measures. The results of Section 4.4 apply provided that $D = \Lambda$, which means that worker's and planner's valuation of a death coincide.

A.2 Planner's solution with risk aversion

Suppose that worker's utility is concave and given by $u(C) = \frac{C^{1-\rho}}{1-\rho}$ where $\rho \in [0,1)$ to ensure positive utility levels. The utilitarian planner maximizes the total utility of the economy

$$\int_0^\infty u(C(t))N(t)e^{-rt}dt.$$

With concave utility and labor market frictions, it is optimal to distribute consumption equally across individuals in each period such that workers are perfectly insured against idiosyncratic labor market shocks as in Merz (1995), which implies $C(t) = \frac{y(m(t))L(t)+zU(t)-cV(t)}{N(t)}$. Substituting this above, the planner maximizes

$$\frac{1}{1-\rho}\int_0^\infty [y(m(t))L(t) + zU(t) - cV(t)]^{1-\rho}N(t)^\rho e^{-rt}dt.$$

Therefore, the planner essentially has Cobb-Douglas utility with weight $1-\rho$ on aggregate output and weight ρ on population size. The first order conditions for m and θ are $y'(m) = \nu C^\rho$ and $c = -p'(\theta)\mu C^\rho$, respectively. The co-states in a steady state satisfy

$$(r+m)\nu = y(m)C^{-\rho} + \frac{\rho}{1-\rho}C^{1-\rho} + \mu s,$$
$$(r+s+m_U+p(\theta)\eta(\theta))\mu = -C^{-\rho}(y-z) + \nu(m-m_U).$$

Combining these equations yields

$$y'(m) = \frac{[r+m_U+p(\theta)\eta(\theta)][y(m)+\frac{\rho}{1-\rho}C] + s[z+\frac{\rho}{1-\rho}C]}{[r+m_U+p(\theta)\eta(\theta)](r+m)+s(r+m_U)}. \tag{31}$$

$$(1-\eta(\theta))\frac{(r+m_U)[y(m)+\frac{\rho}{1-\rho}C] - (r+m)[z+\frac{\rho}{1-\rho}C]}{[r+m_U+p(\theta)\eta(\theta)](r+m)+s(r+m_U)} = \frac{c}{q(\theta)}, \tag{32}$$

Risk aversion therefore effectively raises the flow values of production of employed and unemployed individuals, similar to attributing a non-pecuniary value to death as in Appendix A.1. The difference, however, is, that C in equations (31)–(32) is endogenous.

In the economy without frictions, the optimal mortality rate m^{**} satisfies

$$y'(m^{**}) = \frac{y(m^{**}) + \frac{\rho}{1-\rho}C^{**}}{r+m^{**}} = \frac{y(m^{**})}{(1-\rho)(r+m^{**})}. \tag{33}$$

The last equality follows from the observation that without frictions, all individuals would be employed and there is no need to create vacancies, implying $C^{**} = y(m^{**})$. To compare the optimal mortality rate with and without frictions, first note that in a frictional equilibrium (m^*, θ^*) the left-hand side of (32) must be positive, by which the right-hand side of (31) in optimum is strictly smaller than $[y(m^*) + \frac{\rho}{1-\rho}C^*]/(r+m^*)$. Under the weak assumption that $y(m^*) \geq z - c\theta^*$, it holds that $C^* \leq y(m^*)$, such that $y'(m^*) < \frac{y(m^*)}{(1-\rho)(r+m^*)}$. The concavity of effective output then implies $m^* > m^{**}$.

A.3 Alternative determination schemes for occupational safety

Joint bargaining of wages and safety measures internalizes the labor supply externality in equilibrium. This result holds also if safety levels are determined differently, as long as the outcome maximizes the joint surplus of the match.

As highlighted in Section 4.2, the same bargaining outcome as with joint bargaining can be attained if first a wage schedule $w(m)$ is negotiated by Nash bargaining, i.e. $w(m) = \text{argmax}_w\{(W(m) - U)^\gamma J(m)^{1-\gamma}\}$. Based on this schedule, the mortality rate is determined. Interestingly, it is irrelevant at this point whether another negotiation round takes place or whether one party unilaterally sets m. Since $w(m)$ is such that $W(m) - U = \gamma S(m)$ and $J(m) = (1 - \gamma)S(m)$, we observe

$$\max_m \, (W(m) - U)^\delta J(m)^{1-\delta} = \gamma^\delta (1 - \gamma)^{1-\delta} \max_m S(m).$$

Irrespective of $\delta \in [0, 1]$, the chosen mortality rate maximizes joint surplus. The same is true if m is set *before* the wage negotiation, as the parties anticipate that the resulting joint surplus will be shared according to the Nash rule.

Outcomes may change if the worker cannot verify whether the level of safety measures implemented by the firm after the negotiation is adequate to reach the agreed mortality rate. Indeed, by deviating from the negotiated level of m and underinvesting into safety measures, firms can increase their profit *ex post*. To see this, note that at the contracted wage w, the firm would like to choose m to maximize its surplus J subject to $W \geq U$. The first order condition for an interior optimum is

$$y'(m) = J = \frac{y(m) - w}{r + m + s}.$$

The marginal cost of mortality risk on the right-hand side of this equation is now only the firm's private cost J. The cost of the worker is not taken into account. Comparison with (22) reveals that, irrespective of the negotiated wage, mortality is above the negotiated level. The bargaining outcome therefore does not materialize if firms lack commitment on m.

However, a small change in the bargaining protocol can eliminate the firm's incentive for *ex post* deviations. Suppose that instead of a pair (m, w), firm and worker agree on a wage level w as well as a wage gradient w' that specifies the worker's compensation for additional risk-taking. Presented with such a contract, the firm sets m according to the condition $y'(m) - w' = J$, which defines a function $m(w, w')$. It is easy to see that $\frac{\partial m(w,w')}{\partial w'} < 0$, such that a higher wage gradient reduces the optimal mortality rate chosen by the firm. This insight can be used to show that the Nash bargaining problem for (w, w') subject to $m = m(w, w')$ leads to the conditions (20)–(21). These yield a pair (w, m), from which the wage gradient that establishes m as the firm's optimal mortality rate is set as $w' = y'(m) - J$. This way, the firm's incentive for *ex post* deviations is eliminated, and the equilibrium of Section 4.3 is attained even if firms can only commit to wages and premia for risk-taking.

The provision of occupational safety may also be inhibited by the classical hold-up problem, which arises when safety measures are implemented *before* wages are set, and part of the safety costs are irretrievable.[32] This changes a firm's threat point in the bargain as it would incur a loss if the worker walked away. Assuming sunk costs $d(m) > 0$, the bargaining problem becomes

$$\max_w (W - U)^\gamma (J + d(m))^{1-\gamma},$$

since the firm's outside option is now $-d(m)$. The solution implies $J = (1-\gamma)S - \gamma d(m)$. Assuming that the firm unilaterally chooses the level of safety measures before wages are negotiated, the first order condition for m is $\frac{\partial S}{\partial m} = \frac{\gamma}{1-\gamma} d'(m)$. If higher safety measures require more upfront costs, $d'(m) < 0$, the firm chooses a point on the downwards sloping part of the surplus curve, $\frac{\partial S}{\partial m} < 0$. Therefore, joint surplus is no longer maximized. Furthermore, the optimality condition for m can be written

$$y'(m) - \frac{\gamma}{1-\gamma} d'(m)(r+m+s) = \frac{y(m) + sU}{r+m+s},$$

which shows that the firm's marginal gain of mortality increases because part of the additional expenditures on safety measures cannot be shared with the worker. Even if $d'(m) = 0$, the presence of sunk costs affects the mortality rate via U, as the worker effectively receives a higher share in surplus. In any case, transfers can be used to redistribute a part of the firm's upfront expenditures to the households to restore efficient safety provision.

While in a bargaining setting, hold-up and matching externalities can lead to suboptimal equilibrium outcomes, efficiency may always arise if the labor market is organized differently. Suppose that firms post and commit to contracts (m, w), to which workers apply in the manner of directed search (Moen, 1997; Wright et al., 2021).[33] The directed search equilibrium can be characterized as solution to

$$\max_{(m,w,\theta)} p(\theta)(W - U) \quad \text{s.t.} \quad q(\theta)J = c.$$

It is easy to verify that the equilibrium conditions boil down to planner's conditions (18)–(19). Additionally to internalizing the externalities, directed search gets around the hold-up problem (Acemoglu and Shimer, 1999).

A.4 Two optimal government policies

This section investigates two particular policies that are able to implement the government's optimum $(\bar{m}, \bar{\theta})$ of Section 4.5. To simplify the analysis, we assume that the Hosios condition holds at any θ, i.e. $\eta(\theta) \equiv \gamma$.

Fines for occupational deaths. Suppose that the government fines firms in which a fatal incident occurs. The value of a filled job becomes $rJ = y(m) + t - w - (s+m)(J - V) - md$, where d is the fine collected after a worker's death and t is a lump sum transfer that any operating firm

[32] See Malcomson (1997) for a summary of this literature.

[33] If the actual level of job security provided by the firm is not verifiable, the contracts can equivalently be written over (w, w') similar to the discussion above.

receives from the government.[34] With this policy, the job creation curve in the decentralized economy (25) becomes

$$(1-\gamma)\frac{(r+m_U)(y(m)+t-md)-(r+m)z}{(r+m_U+p(\theta)\gamma)(r+m)+(r+m_U)s}=\frac{c}{q(\theta)}.$$

For the equilibrium to lie on the planner's job creation curve (18), the terms arising from the policy must cancel in equilibrium, i.e. $t=\bar{m}d$. This implies that the government's budget is balanced. Furthermore, the policy modifies equation (26) to

$$y'(m)=\frac{(r+m_U+p(\theta)\gamma)(y(m)+t+rd)+s(z+(r+m_U)d)}{(r+m_U+p(\theta)\gamma)(r+m)+(r+m_U)s}.$$

Evaluating this in equilibrium, considering $t=\bar{m}d$, pins down the penalty required to implement the optimum,

$$d=y'(\bar{m})-\frac{(r+m_U+p(\bar{\theta})\gamma)y(\bar{m})+sz}{(r+m_U+p(\bar{\theta})\gamma)(r+\bar{m})+(r+m_U)s}, \tag{34}$$

which is positive for $\bar{m}<m^*$. Setting the fine according to (34) effectively increases the marginal cost of mortality risk such that marginal costs and benefits are equalized at the mortality rate $\bar{m}$ targeted by the government.

Mortality-dependent tax. Suppose that the government instead levies a tax $T(m)$ on *all* firms. This effectively changes effective output from $y(m)$ to $y(m)-T(m)$. The job creation curve in the decentralized economy (25) therefore becomes

$$(1-\gamma)\frac{(r+m_U)(y(m)-T(m))-(r+m)z}{(r+m_U+p(\theta)\gamma)(r+m)+(r+m_U)s}=\frac{c}{q(\theta)}.$$

For the equilibrium to lie on the planner's job creation curve (18), the terms arising from the policy must cancel, i.e. $T(\bar{m})=0$, such that in equilibrium the tax is zero. Furthermore, the policy modifies equation (26) to

$$y'(m)-T'(m)=\frac{(r+m_U+p(\theta)\gamma)(y(m)-T(m))+sz)}{(r+m_U+p(\theta)\gamma)(r+m)+(r+m_U)s}.$$

Evaluating this in equilibrium, considering $T(\bar{m})=0$, reveals $T'(\bar{m})=d$ with d given in (34). Hence, although the tax is zero in equilibrium, the tax schedule is upwards sloping, which increases the marginal cost of mortality risk such that marginal costs and benefits of mortality are equalized at $\bar{m}$.

Note that the above conditions only pin down the level and the slope of $T(m)$ at $m=\overline{m}$, but not at other points. The specific shape of T in fact does not matter as long as no additional equilibrium arises. This is granted if the altered effective output function $y(m)-T(m)$ continues to satisfy Assumption 1. One tax schedule with this property is $T(m)=\lambda[y(m)-y(\bar{m})]$, with

[34] Since the firm is left with a vacancy if the worker dies, the penalty could be collected already at the date of hiring and refunded when the match terminates for a reason other than death.

which the government captures a share λ of the production gain that arises from producing with a mortality rate above its target. It is clear that $T(\bar{m}) = 0$ and $T'(\bar{m}) = \lambda y'(\bar{m})$, which reveals that $\lambda = \frac{d}{y'(\bar{m})}$ implements the desired equilibrium.

The advantage of the mortality-dependent tax is that no actual payments occur since the tax is zero in equilibrium, while the slope of the tax schedule provides the right incentives to the parties to implement $\bar{m}$. Despite the theoretical appeal of this policy, its practical implementation requires information on firm-level mortality rates which need to be estimated. This is not feasible for small or short-lived firms. Charging fines for occupational deaths instead only requires information about whether a work-related death has occurred or not at a given point in time.

Implementing the Hosios condition. The above analysis assumed that the Hosios condition is satisfied. If this is not the case and the government cannot directly affect the bargaining weights, the proposed policies can be adjusted to take this into account. If $\gamma < \eta$, part of the revenue from fines or taxes should be redistributed to households. Otherwise, part of household income should be taxed and redistributed to firms.

B Mathematical appendix

This section contains auxiliary results and proofs to the propositions stated in the main text.

B.1 Auxiliary results

Lemma 1. *The function* $\phi(m) := \frac{y(m)}{r+m}$ *satisfies* $\lim_{m\to\infty} \phi(m) = 0$. *It is unimodal with a single peak* $\overline{m} > 0$*, which satisfies* $\frac{y(\overline{m})}{r+\overline{m}} > \frac{z}{r+m_U}$.

Proof. Assumption 1(i) implies $\lim_{m\to\infty} \phi(m) = 0$ by L'Hopital's rule. The derivative is $\phi'(m) = \frac{1}{r+m}[y'(m) - \frac{y(m)}{r+m}]$. At any point that satisfies $\phi'(m) = 0$, the second derivative is $\frac{y''(m)}{r+m} < 0$. Hence any local optimum of ϕ is a maximum. Assumption 1(ii) guarantees an $\tilde{m} > 0$ such that $\phi(\tilde{m}) > \frac{z}{r+m_U} \geq 0$. As ϕ asymptotically approaches 0, it either has a single peak $\overline{m} > 0$ or is monotonically decreasing. The latter is ruled out by Assumption 1(iii), which implies $\phi(0) < \phi(\tilde{m})$. Finally, $\phi(\overline{m}) \geq \phi(\tilde{m}) > \frac{z}{r+m_U}$, since $\overline{m}$ maximizes ϕ. □

Lemma 2. *Equation* (18) *defines a function* $\theta^*(m)$ *with the following properties:*

(i) the domain of θ^* *is a non-empty interval* $M = (\underline{m}, \overline{m}) \subset \mathbb{R}^+$ *whose boundaries satisfy* $\frac{y(m)}{r+m} = \frac{z}{r+m_U}$,

(ii) the sign of $\frac{d\theta^*}{dm}$ *is the opposite of* $\frac{\partial\mu}{\partial m}$*, where* μ *is given in* (17),

(iii) the function is unimodal with a single peak and approaches zero at the boundaries of M.

Proof. Property (i): Since $q(\theta)$ is positive for any finite θ by Assumption 2(ii), a solution to (18) can only exist if $\mu < 0$, which requires $m \in M := \{m \geq 0 : \frac{y(m)}{r+m} > \frac{z}{r+m_U}\}$. On the other hand, for any $m \in M$, the properties of Assumption 2 ensure that (18) has a unique solution $\theta^*(m) > 0$. Hence the domain of θ^* is M, which by Assumption 1(iii) does not include zero. The unimodality result of Lemma 1 implies that M is a non-empty open interval.

Property (ii): Applying the implicit function theorem to (18) gives

$$\frac{d\theta^*}{dm} = \frac{-(1-\eta(\theta))\frac{\partial\mu}{\partial m}}{(1-\eta(\theta))\frac{\partial\mu}{\partial\theta} - \eta'(\theta)\mu - \frac{c}{q(\theta)^2}q'(\theta)}$$

with μ given in (17). Due to $\mu < 0$, $\frac{\partial\mu}{\partial\theta} > 0$, as well as Assumption 2, the denominator is strictly positive. Furthermore, $1-\eta(\theta) = \frac{p'(\theta)\theta}{p(\theta)} > 0$, such that the sign of $\frac{d\theta^*}{dm}$ equals the sign of $-\frac{\partial\mu}{\partial m}$.

Property (iii): At the boundaries of M, $\frac{y(m)}{r+m} \to \frac{z}{r+m_U}$ and thus $\frac{c}{q(\theta)} \to 0$. By Assumption 2(ii), this implies $\theta \to 0$. Since $\theta(m) > 0$ for $m \in M$, θ must attain a local maximum in M. This maximum is unique provided that no inner local minimum exists. Property (ii) of this Lemma implies that $\frac{d\theta^*}{dm} = 0$ if and only if $\frac{\partial\mu}{\partial m} = 0$. Every such point is a local maximum of θ^*, since $\frac{d^2\theta^*}{dm^2}$ becomes proportional to $-\frac{\partial^2\mu}{dm^2} = \frac{ry''(m)}{(r+m_U+p(\theta)\eta(\theta))(r+m)+s(r+m_U)} < 0$. By continuity, $\frac{d\theta^*}{dm}$ cannot change sign more than once, such that the maximum is unique. □

Lemma 3. *The equilibrium value of unemployment U is unimodal in γ and peaks at $\gamma = \eta(\theta)$.*

Proof. Differentiating (24) with respect to γ gives $\frac{dU}{d\gamma} = \frac{\partial U}{\partial m}\frac{dm}{d\gamma} + \frac{\partial U}{\partial[p(\theta)\gamma]}\frac{d[p(\theta)\gamma]}{d\gamma}$. It is straightforward to show $\frac{\partial U}{\partial m} = 0$ and $\frac{\partial U}{\partial[p(\theta)\gamma]} = \frac{r+m+s}{(r+m_U+p(\theta)\gamma)(r+m)+(r+m_U)s}S$. Hence the sign of $\frac{dU}{d\gamma}$ coincides with the sign of $\frac{d[p(\theta)\gamma]}{d\gamma}$, which is shown to equal the sign of $\eta(\theta)-\gamma$ in the proof of Proposition 6. The rest of the proof is analogous to there. □

B.2 Proofs of propositions

Proof of Proposition 1. We first show that (5) defines a unique mortality rate. Note that (5) corresponds to the first order condition of $\max_m \frac{y(m)}{r+m}$. By Lemma 1, the objective function is unimodal with a single peak, such that (5) is satisfied by exactly one m.

Next, note that (5) was obtained assuming $U < N$. The maximized value of the Hamiltonian is $\mathcal{H}^{**} = \frac{ry(m^{**})}{r+m^{**}}(N-U)+zU+\frac{y(m^{**})}{r+m^{**}}[B-m_U U]$. To determine the optimal value of U, observe $\frac{\partial\mathcal{H}^{**}}{\partial U} = z - \frac{r+m_U}{r+m^{**}}y(m^{**})$. As m^{**} maximizes $\frac{y(m)}{r+m}$, the derivative is strictly negative by Lemma 1. Therefore, $U^{**} = 0$, and the initial assumption is satisfied. □

Proof of Proposition 2. By Lemma 2, $\theta^*(m)$ has a unique peak characterized by $\frac{\partial\mu}{\partial m} = 0$ where

$$\frac{\partial\mu}{\partial m} = \frac{r+m_U}{[r+m_U+p(\theta)\eta(\theta)](r+m)+s(r+m_U)}\left\{\frac{[r+m_U+p(\theta)\eta(\theta)]y(m)+sz}{[r+m_U+p(\theta)\eta(\theta)](r+m)+s(r+m_U)} - y'(m)\right\}.$$

Hence the point (m,θ) that maximizes $\theta^*(m)$ solves the planner's problem because it satisfies (18)–(19). On the other hand, any solution satisfies $\frac{\partial\mu}{\partial m} = 0$ and therefore corresponds to an interior extremum of $\theta^*(m)$. Since $\theta^*(m)$ is unimodal, the only interior extremum is the unique global maximum. □

Proof of Proposition 3. Equation (19) can be rewritten $y'(m) = \frac{y(m)+\phi z}{r+m+\phi(r+m_U)}$. For $\phi = 0$, the condition simplifies to (5). The implicit function theorem yields $\frac{dm}{d\phi} = \frac{\mu}{y''(m)[r+m+\phi(r+m_U)]}$, which is positive since $y''(m) < 0$ and $\mu < 0$. □

Proof of Proposition 4. The result immediately follows from Lemma 2 and Proposition 2 by setting $\eta(\theta) \equiv \gamma$ and noting $\mu = -S$. □

Proof of Proposition 6. I first verify that like in the basic DMP model, the equilibrium tightness is strictly decreasing in γ. Consider the total derivative of (25),

$$\left[(1-\gamma)\frac{\partial S}{\partial \gamma} - S\right] d\gamma + \left[(1-\gamma)\frac{\partial S}{\partial \theta} + c\frac{q'(\theta)}{q^2(\theta)}\right] d\theta + (1-\gamma)\frac{\partial S}{\partial m} dm = 0,$$

where all expressions are evaluated in equilibrium and S is given in (23). Since m maximizes S, the last term is zero and evaluating the remaining terms yields

$$\frac{d\theta}{d\gamma} = -\frac{(r+m_U+p(\theta))(r+m)+(r+m_U)s}{[p(\theta)\gamma+\eta(\theta)(r+m_U)](r+m)+\eta(\theta)(r+m_U)s} \cdot \frac{\theta}{1-\gamma} < 0.$$

Second, observe from (26) that the equilibrium mortality rate depends on γ only via the joint term $p(\theta)\gamma$. The implicit function theorem reveals

$$\frac{\partial m}{\partial[p(\theta)\gamma]} = \frac{y(m)-y'(m)(r+m)}{y''(m)[(r+m_U+p(\theta)\gamma)(r+m)+(r+m_U)s]} < 0.$$

The sign follows from $y'' < 0$ and substituting (26), by which $y(m) > y'(m)(r+m)$. Furthermore,

$$\frac{d[p(\theta)\gamma]}{d\gamma} = p(\theta) + p'(\theta)\gamma\frac{d\theta}{d\gamma} = p(\theta)\left[1 + (1-\eta(\theta))\frac{d\theta}{d\gamma}\frac{\gamma}{\theta}\right].$$

Substituting $\frac{d\theta}{d\gamma}$ from above and collecting terms yields

$$\frac{d[p(\theta)\gamma]}{d\gamma} = p(\theta)\frac{(r+\gamma p(\theta))(r+m)+rs}{[\gamma p(\theta)+\eta(\theta)r](r+m)+\eta(\theta)rs}\frac{\eta(\theta)-\gamma}{1-\gamma}.$$

Putting things together, the sign of $\frac{dm}{d\gamma} = \frac{\partial m}{\partial[p(\theta)\gamma]}\frac{d[p(\theta)\gamma]}{d\gamma}$ equals the sign of $\gamma - \eta(\theta)$. Since $\frac{d\theta}{d\gamma} < 0$ and $\eta' \geq 0$, it follows that $\gamma - \eta(\theta)$ is strictly increasing in γ. Therefore, m has a unique minimum, which satisfies $\gamma = \eta(\theta)$. □

Proof of Proposition 7. With an optimal policy, the equilibrium $(\bar{m}, \bar{\theta})$ lies on the planner's job creation curve and therefore solves the planner's problem for fixed $m = \bar{m}$. Furthermore, note that evaluating the Hamiltonian (10) in a steady state gives the associated level of output, $\mathcal{H}(m) = y(m)L + zU - cV$. The proof of the proposition relies on a Taylor series expansion of $\mathcal{H}$ around m^*, $\mathcal{H}(m) - \mathcal{H}(m^*) = \mathcal{H}'(m^*)(m-m^*) + \frac{\mathcal{H}''(m^*)}{2}(m-m^*)^2 + \mathcal{O}(m^3)$. Implicit differentiation of (10) yields

$$\mathcal{H}'(m) = [y'(m) - \nu](N - U) - [c + \mu p'(\theta)]\tfrac{d\theta}{dm}U \\ + [y(m) + \mu s - m\nu]\tfrac{dN}{dm} + [z - c\theta - y(m) - (s + p(\theta) + m_U)\mu + \nu(m - m_U)]\tfrac{dU}{dm}.$$

Conditions (11)–(12) as well as the steady state versions of (13)–(14) for $r = 0$ reveal that all bracketed terms evaluate to zero in the planner's optimal solution, such that $\mathcal{H}'(m^*) = 0$. The second derivative of $\mathcal{H}(m)$ is

$$\mathcal{H}''(m) = [y''(m) - \tfrac{d\nu}{dm}](N - U) - \big[\tfrac{d\mu}{dm}p'(\theta) + \mu p''(\theta)\tfrac{d\theta}{dm}\big]\tfrac{d\theta}{dm}U + [y'(m) + \tfrac{d\mu}{dm}s - \nu - m\tfrac{d\nu}{dm}]\tfrac{dN}{dm} \\ + \big[-c\tfrac{d\theta}{dm} - y'(m) - (s + p(\theta) + m_U)\tfrac{d\mu}{dm} - p'(\theta)\tfrac{d\theta}{dm}\mu + \tfrac{d\nu}{dm}(m - m_U) + \nu\big]\tfrac{dU}{dm} \\ + [y'(m) - \nu](\tfrac{dN}{dm} - \tfrac{dU}{dm}) - [c + \mu p'(\theta)](\tfrac{d^2\theta}{dm^2}U + \tfrac{d\theta}{dm}\tfrac{dU}{dm}) \\ + [y(m) + \mu s - m\nu]\tfrac{d^2N}{dm^2} + [z - c\theta - y(m) - (s + p(\theta) + m_U)\mu + \nu(m - m_U)]\tfrac{dU^2}{dm^2}.$$

By the same argument as above, the last two lines evaluate to zero for $r = 0$ and $m = m^*$. Furthermore, it can be shown that $\frac{d\theta}{dm} = 0$ implies $\frac{d\mu}{dm} = 0$ and $\frac{d\nu}{dm} = 0$ at $m = m^*$, such that $\mathcal{H}''(m^*) = y''(m^*)(N - U)$. □

C Robustness checks

Self-employment. The CFOI public use file does not allow to disaggregate fatalities by type of employment and age group at the same time, such that all our variables also include self-employed workers, while our theoretical model relates just to dependent employment. For our purposes, this is only problematic if the estimated positive effect of search frictions originates exclusively from changes in the risk-taking of self-employed. To check whether this could be the case, we add an interaction term between the unemployment rate and share of self-employed. If the effect of search frictions comes through higher mortality of self-employed, this interaction should be positive. However, the interaction turns out to be negative and insignificant, and has hardly any effect on the estimated marginal effect of the unemployment rate. This holds for any measure of search frictions considered above. As additional robustness check, we repeat our main regressions on non-age structured CFOI and CPS data that excludes self-employed workers. The estimated marginal effect of unemployment on mortality is about 75% higher than in Table 1, yet less precisely estimated due to a much smaller sample size.

Industrial composition and unobserved regional differences. The observed positive correlation between unemployment and mortality may be driven by regional differences in the distribution of occupations across industries. States dominated by traditional manufacturing may at the same time experience high mortality and high unemployment in occupations associated with this declining industry. In columns (1) and (2) of Table D3 we control for industrial composition using the cell-specific shares of the 24 NAICS 2-digit industries as additional explanatory variables, observing little changes on our coefficient of interest.

Besides industrial composition, there may be unobserved factors due to which working in the same occupation is more risky in one region than in another, and that may affect a worker's decision on where to work. For instance, a truck driver in Alaska is more likely to face hazardous road conditions than a truck driver in Florida. If the higher risk is rewarded with a sufficiently higher wage, individuals may be tempted to look for a job in the high mortality state, adding to the unemployment rate there. However, also the opposite seems plausible and individuals may prefer to look for a job in the low mortality region, biasing our estimates downwards. To control for these unobserved regional differences within occupations, we interact state fixed effects with occupational fixed effects in columns (3) and (4) of Table D3. The results remain close to our main estimates.

Occupational switches. The CPS assigns unemployed to the occupation of their last job. In our sample 53.4% of unemployed take up their next job in a different occupation, such that computing the number of unemployment based on the previous occupation may not accurately reflect the true number of job seekers in a given cell. The detected positive correlation between unemployment and mortality could be spurious if unemployed tend to move from high to low mortality occupations, without this being reflected in a decreasing (increasing) unemployment rate in the high (low) mortality occupation. As a first check, we regress the incidence of occupational switches among the unemployed of a given cell on the fatality rate of workers in the same cell, controlling for our fixed effects. The coefficient estimate is very precisely estimated at 0, suggesting the absence of the speculated channel. As a second check, we create an adjusted version of the unemployment rate that takes into account observed switching patterns between occupations. To this purpose, we exploit the panel dimension of the CPS and identify all UE transitions during our period of observation. From these, we create age-specific Markov transition matrices M_a between 2-digit occupations. Based on the observed transition probability M_{aij} between any two occupations i and j in age group a, we assume that a share M_{aij} of age a unemployed who were previously employed in occupation i looks for their next job in occupation j.[35] The hypothetical number of job seekers in age group a, occupation j, and state s is then $\tilde{U}_{ajs} = \sum_i U_{ais} M_{aij}$, where U_{ais} is the number of unemployed reported by the CPS in cell (ais). The adjusted unemployment rate is constructed from this figure and serves as the main variable of interest in Table D4. The coefficient estimates of all specifications and are comparable to the NB2 estimates of Table 1.

Sampling variation. Although our cell-specific variables are based on 5.6 million individual observations and therefore on average 1,000 observations per cell, some cells may contain insufficient observations to accurately measure the variables included in our regression model. The panel structure of the CPS further reduces the effective sample size in a cell due to correlated observations. The applied count data models can potentially mitigate such problems. A lack of individual observations is more likely in cells with low employment. These cells, however,

[35] While we compute this matrix separately for each age group, we do not differentiate by state, as the probability of switching occupations appears to be similar across states.

are down-weighted in the estimation process because the score functions of the Poisson and the Negative Binomial model put higher weight on contributions of cells with a large number of exposed individuals.[36] Cells with large sampling error should therefore have little impact on the ML estimates.

We conduct two robustness checks to verify this suspicion. First, we restrict the regression sample to cells with at least 300 individual observations, which reduces the sample size by 25%. Columns (1) and (2) in Table D5 show that the coefficient estimates remain similar to Table 1 while the standard error increases. As a second check, we take employment and demographic information from a different source, namely the American Community Survey (ACS).[37] The ACS is conducted annually by the US Census Bureau on 3.5 million households, whereas the CPS only covers 60,000 households. With the ACS, the number of individual observations used to construct our cell-specific variables increases to 10.9 million individual observations. Since the ACS is not a panel survey, these observations are independent across waves. While the larger sample and the absence of a panel structure help to reduce sampling error, the ACS does not entail questions about unionization, duration of unemployment or employment transitions, such that we can only partially replicate our main regressions of Table 1. Nevertheless, column (3) and (4) of Table D5 shows that the marginal effects of unemployment estimated from ACS data come close to the CPS estimates, although with a larger standard error.

[36]The score functions of both models can be expressed as $\sum_{ais}[\frac{D_{ais}}{N_{ais}} - \mu_{ais}]x_{ais}\omega_{ais}$. For the Poisson model, the weight is $\omega_{ais} = N_{ais}$. For the NB2 model, the weight is $\omega_{ais} = \frac{N_{ais}}{1+\alpha\mu_{ais}N_{ais}}$, which is monotonically increasing in N_{ais}.

[37]We used the IPUMS version of the ACS provided by Ruggles et al. (2022), downloaded on Oct. 6, 2022.

D Additional tables

variable	population-level	cell-level			
		mean	st.dev.	min	max
deaths from occupational injuries	32,979	4.47	15.3	0	323
employment (in 100,000)	10,797	1.925	3.173	0	44.19
full time equivalents (in 100,000)	10,747	1.916	3.215	0	48.61
mean usual hours worked per week	39.82	39.53	3.77	22.36	57.22
share male workers	0.530	0.551	0.259	0	1
share non-hispanic white workers	0.643	0.710	0.204	0	1
share non-hispanic black workers	0.112	0.099	0.121	0	0.91
share non-hispanic Asian workers	0.061	0.050	0.087	0	0.92
share hispanic workers	0.166	0.113	0.141	0	1
share self-employed workers	0.095	0.091	0.105	0	0.78
share high-school graduates	0.925	0.934	0.094	0.23	1
share college graduates	0.475	0.488	0.279	0	1
share workers covered by a union contract	0.127	0.113	0.122	0	0.77
mean age of workers (in years)	41.30	39.94	13.21	20.86	60.51
unemployment (in 100,000)	656.7	0.110	0.210	0	3.44
unemployment rate	0.057	0.053	0.041	0	0.68
mean months in unemployment	7.190	6.278	3.393	0.23	27.46
share of long-term unemployed	0.248	0.205	0.169	0	1

Occupational deaths computed from the Census of Fatal Occupational Injuries (CFOI) public use files, all other variables from the Current Population Survey (CPS) provided by Flood et al. (2021), pooled years 2011–2018. Population-level figures are computed over the pooled population, while cell-level figures are computed from the 5,610 state-occupation-age group cells used in the regression analysis.

Table D1. Sample statistics

	dependent variable: number of occupational fatalities	
	Poisson	*NB2*
	(1)	(2)
unemployment rate	2.222***	2.603***
	(0.697)	(0.621)
mean hours worked	−0.363***	−0.372***
	(0.139)	(0.117)
(mean hours worked)^2	0.005***	0.005***
	(0.002)	(0.001)
mean age	−0.044	−0.045
	(0.061)	(0.061)
share male workers	0.349	0.473
	(0.465)	(0.371)
share white workers (non-hispanic)	−0.034	−0.104
	(1.114)	(1.290)
share black workers (non-hispanic)	0.138	−0.159
	(1.121)	(1.309)
share Asian workers (non-hispanic)	−1.329	−1.658
	(1.555)	(1.579)
share hispanic workers	0.593	0.847
	(1.021)	(1.275)
share self-employed workers	2.480***	2.459***
	(0.294)	(0.351)
share high-school graduates	0.297	0.228
	(0.433)	(0.452)
share college graduates	−0.072	−0.115
	(0.371)	(0.346)
share workers covered by a union contract	−0.205	−0.555*
	(0.260)	(0.311)
age group × occupation FE	✓	✓
state FE	✓	✓
observations	5,606	5,606
overdispersion	0.044***	0.262***

Poisson and Negative Binomial (NB2) regressions on state-occupation-age group cells with the number of occupational fatalities as dependent variable and full-time equivalent workers as exposure variable. For Poisson, *overdispersion* reports the coefficient estimate of α in the OLS regression $Var(D|\mathcal{X}) = \mathbb{E}(D|\mathcal{X}) + \alpha[\mathbb{E}(D|\mathcal{X})]^2 + \varepsilon$ using Poisson fitted values, see Cameron and Trivedi (1990). For NB2, *overdispersion* gives the MLE of α based on a Negative Binomial distribution for $D|\mathcal{X}$. In both cases, significant deviations from 0 indicate inadequacy of the Poisson model. Standard errors are clustered at the state level. Coefficient significance levels: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table D2. Effect of unemployment on mortality from occupational injuries (full table)

	dependent variable: number of occupational fatalities			
	Poisson	*NB2*	*Poisson*	*NB2*
	(1)	(2)	(3)	(4)
unemployment rate	1.966***	2.659***	2.684***	2.704***
	(0.559)	(0.597)	(0.707)	(0.701)
age group × occupation FE	✓	✓	✓	✓
state FE	✓	✓	✓	✓
state × occupation FE			✓	✓
demographic characteristics	✓	✓	✓	✓
industry shares	✓	✓	✓	✓
observations	5,606	5,606	5,606	5,606
overdispersion	0.046***	0.264***	0.007***	0.020***

Poisson and Negative Binomial (NB2) regressions on state-occupation-age group cells with the number of occupational fatalities as dependent variable and full-time equivalents as exposure variable. Demographic characteristics include share of male workers, share of white, black and Asian non-hispanic workers, share of hispanic workers, share of high-school and college graduates, share of workers covered by a union contract, mean age, and a quadratic polynomial in mean hours worked. For Poisson, *overdispersion* reports the coefficient estimate of α in the OLS regression $Var(D|\mathcal{X}) = \mathbb{E}(D|\mathcal{X}) + \alpha[\mathbb{E}(D|\mathcal{X})]^2 + \varepsilon$ using Poisson fitted values, see Cameron and Trivedi (1990). For NB2, *overdispersion* gives the MLE of α based on a Negative Binomial distribution for $D|\mathcal{X}$. In both cases, significant deviations from 0 indicate inadequacy of the Poisson model. Standard errors are clustered at the state level. Coefficient significance levels: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table D3. Effect of unemployment on mortality from occupational injuries controlling for industry shares and unobserved regional variation within occupation

	dependent variable: number of occupational fatalities			
	Poisson	*NB2*	*Poisson*	*NB2*
	(1)	(2)	(3)	(4)
adjusted unemployment rate	2.152**	1.985**	2.670***	2.279***
	(0.850)	(0.859)	(0.878)	(0.731)
age group × occupation FE	✓	✓	✓	✓
state FE	✓	✓	✓	✓
demographic characteristics			✓	✓
observations	5,609	5,609	5,606	5,606
overdispersion	0.047***	0.300***	0.044***	0.262***

Poisson and Negative Binomial (NB2) regressions on state-occupation-age group cells with the number of occupational fatalities as dependent variable and full-time equivalents as exposure variable. Demographic characteristics include share of male workers, share of white, black and Asian non-hispanic workers, share of hispanic workers, share of high-school and college graduates, share of workers covered by a union contract, mean age, and a quadratic polynomial in mean hours worked. For Poisson, *overdispersion* reports the coefficient estimate of α in the OLS regression $Var(D|\mathcal{X}) = \mathbb{E}(D|\mathcal{X}) + \alpha[\mathbb{E}(D|\mathcal{X})]^2 + \varepsilon$ using Poisson fitted values, see Cameron and Trivedi (1990). For NB2, *overdispersion* gives the MLE of α based on a Negative Binomial distribution for $D|\mathcal{X}$. In both cases, significant deviations from 0 indicate inadequacy of the Poisson model. Standard errors are clustered at the state level. Coefficient significance levels: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table D4. Effect of unemployment on mortality from occupational injuries after adjusting for occupational switches

	dependent variable: number of occupational fatalities			
	CPS, selected cells		ACS, all cells	
	Poisson	*NB2*	*Poisson*	*NB2*
	(1)	(2)	(3)	(4)
unemployment rate	2.365**	2.476**	2.365**	2.111**
	(1.029)	(1.055)	(0.969)	(1.012)
age group × occupation FE	✓	✓	✓	✓
state FE	✓	✓	✓	✓
demographic characteristics	✓	✓	✓	✓
observations	4,260	4,260	5,608	5,608
overdispersion	0.042***	0.237***	0.042***	0.259***

Poisson and Negative Binomial (NB2) regressions on state-occupation-age group cells with the number of occupational fatalities as dependent variable and full-time equivalents as exposure variable. Columns (1) and (2) exclude the 25% cells with the least individual observations. Columns (3) and (4) are based on data from the American Community Survey (ACS). Demographic characteristics include share of male workers, share of white, black and Asian non-hispanic workers, share of hispanic workers, share of high-school and college graduates, share of workers covered by a union contract (CPS only), mean age, and a quadratic polynomial in mean hours worked. For Poisson, *overdispersion* reports the coefficient estimate of α in the OLS regression $Var(D|\mathcal{X}) = \mathbb{E}(D|\mathcal{X}) + \alpha[\mathbb{E}(D|\mathcal{X})]^2 + \varepsilon$ using Poisson fitted values, see Cameron and Trivedi (1990). For NB2, *overdispersion* gives the MLE of α based on a Negative Binomial distribution for $D|\mathcal{X}$. In both cases, significant deviations from 0 indicate inadequacy of the Poisson model. Standard errors are clustered at the state level. Coefficient significance levels: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table D5. Effect of unemployment on mortality from occupational injuries estimated from different samples