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Online Appendix: How Substitutable Are Workers? – Evidence from Worker Deaths

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A-1 Structural Model and Estimation

We provide derivations and additional details following and building on the model in Kline et al. (2019).

A-1.1 Model

A-1.1.1 FOCs

To derive (7) and (8), we compute partial derivatives of the profits function with respect to the choice variables:

$$\frac{\partial \pi}{\partial w^I} = MRP\frac{\eta}{w^I - w^m}G(w^I)I - w^I\frac{\eta}{w^I - w^m}G(w^I)I - G(w^I)I,$$
$$\frac{\partial \pi}{\partial N} = MRP - w^m - c'\left(\frac{N}{I}\right).$$

Re-arranging then yields (7) and (8).

For the dynamic model, the FOCs become:

$$MRP + \beta V'(G(w_t^I)I_t + N_t) = w_t^I + \frac{w_t^I - w^m}{\eta}, \quad (1)$$
$$MRP + \beta V'(G(w_t^I)I_t + N_t) = w^m + c'\left(\frac{N_t}{I_t}\right). \quad (2)$$

A-1.1.2 Comparative Statics

We develop intuition about the model's behavior by studying comparative statics in the simpler case of the static model. Proposition A-1.1 summarizes these results. See Appendix A-1.5 for proofs.

Proposition A-1.1. *The responses of incumbent wages and hiring to a change in the number of incumbents are summarized by the following system of equations*

$$
\begin{aligned}
\frac{dMRP}{dI} &= \frac{1+\eta}{\eta}\frac{dw^I}{dI}, \\
\frac{dMRP}{dI} &= \frac{c''\left(\frac{N}{I}\right)}{I}\left(\frac{dN}{dI} - \frac{N}{I}\right), \\
\frac{dMRP}{dI} &= -\frac{1}{\epsilon}MRP\frac{dL}{dI}\frac{1}{L}, \\
\frac{dL}{dI} &= \frac{dN}{dI} + I\eta G(w^I)\frac{1}{w^I - w^m}\frac{dw^I}{dI} + G(w^I).
\end{aligned}
\tag{3}
$$

From this system of equations, we deduce the following results.

(i) Hiring costs are strictly convex if and only if incumbent wages decrease with I.
(ii) If hiring costs are linear, then incumbent wages do not vary with I, and hiring strictly decreases with I.
(iii) The change in hiring satisfies $dN/dI - N/I < 0$.
(iv) If we neglect the scale effect from a change in I to hiring costs, then hiring strictly decreases with I.

Proposition A-1.1 highlights how the model requires strictly convex hiring costs to match the data. Without strictly convex costs, incumbent wages would not change after an incumbent death. The firm instead responds by fully replacing the incumbent with outsiders. According to claim (iii), we should also expect the hiring of outsiders to increase after an incumbent death when the scale effect to hiring costs is not too large.

Connection with Empirical Results.

The observed wage response implies that hiring costs are convex. The identified responses of wages and hiring to an incumbent death are therefore consistent with each other.

A-1.2 Estimation Strategy

To implement the estimation, we adopt the mathematical program with equilibrium constraints (MPEC) approach proposed by Su/Judd (2012). The typical approach for estimating equilibrium models is the following procedure.

1. Solve the model accurately given a fixed set of parameters.
2. Use an optimization algorithm or root solver to update the parameters.
3. Iterate until a solution is found.

The issue with this approach is that step 1 is usually time-consuming. MPEC bypasses this issue by reframing the estimation problem as a constrained optimization problem. The targeted moments comprise the objective to minimize while equilibrium conditions are imposed as constraints. This approach speeds up computation by only solving the model accurately for the final set of parameters. Most algorithms for constrained optimization problems allow constraints to be violated during the parameter search and are robust to these violations. As a result, the algorithm is more efficient by not repeatedly solving the model for parameters that are not close to hitting the targeted moments.

A-1.2.1 Baseline Dynamic Model

Suppose the firm is in a steady state, and at time $t = 0$ it experiences an unexpected decrease in the number of its incumbent workers. Note that this is not an innocuous assumption because it is possible many firms were still on a transition path across the time horizon for which we have data. Nevertheless, we can match the adjustments over time of wages, hiring, and total employment to those estimated by the paper's event study.

To implement the method of simulated moments, we follow Su/Judd (2012) and minimize squared deviations from the targeted moments subject to the model's equilibrium conditions holding as constraints. The dynamic equilibrium conditions are infinite dimensional due to the value function. We obtain a finite-dimensional representation of the problem by interpolating the value function with Chebyshev polynomials. To double-check the accuracy of our method, we also used value function iteration rather than enforcing equilibrium conditions as constraints.

We estimate six parameters because we have six moments, hence the model is exactly identified. The six parameters to estimate are γ, λ, η, $\overline{w}$, ϵ, and P^0. We normalize labor productivity to $T = 1$ since it is not separately identified from P^0. We set $\beta = 0.96$ to match a 4% annual discount rate, which is standard in the literature. And we set w^M equal to the average wages of new hires, Euro 17163 in the data.

A-1.3 Extension to Bargaining

In this extension, we relax the wage posting assumption in the baseline static model to allow Nash bargaining over incumbent wages.

A-1.3.1 Firm's Problem

Given a wage w^I, firms solve

$$\max_N P^0(G(w^I)I+N)^{1-1/\epsilon} - c\left(\frac{N}{I}\right)I - w^m N - w^I G(w^I)I. \tag{4}$$

As before, the FOC is

$$MRP = w^m + c'(N/I).$$

This equation implicitly defines N as a function of w^m, w^I, and I. Let $\nu(w^I)$ denote that dependence. We suppress w^m and I because they are irrelevant to the Nash bargaining problem.

The Nash bargaining problem for wages is:

$$\max_{w^I} \left(w^I - w^m\right)^{\phi} \left(\Pi(w^I, I) - \underline{\Pi}\right)^{1-\phi}, \tag{5}$$

where $\Pi(w^I, I)$ is firm j's profits after setting a wage of w^I for incumbents and arriving into the period with I incumbents; and $\underline{\Pi}$ are the profits when the firm has no incumbents and chooses N to maximize their profits. We assume that a union negotiates on behalf of incumbents; the union cares equally about every incumbent; every incumbent receives the same wage; and the union bargains under the assumption that all incumbents remain rather than account for the probability that some incumbents will leave. We assume that if bargaining fails, then all incumbents leave, and the firm must produce with only newly hired labor. On the other hand, incumbents can find a job at the competitive market wage. Transform the objective function by taking logs. The FOC is:

$$0 = \phi\frac{1}{w^I - w^m} + (1-\phi)\frac{\partial_{w^I}\Pi(w^I, I)}{\Pi(w^I, I) - \underline{\Pi}}. \tag{6}$$

The profits function is

$$\Pi(w^I, I) = P^0(G(w^I)I + \nu(w^I))^{1-1/\epsilon} - c\left(\frac{\nu(w^I)}{I}\right)I - w^m\nu(w^I) - w^I G(w^I)I,$$

so the partial w.r.t. w^I is

$$\begin{aligned}
\partial_{w^I}\Pi(w^I, I) &= P_0^j T^{1-1/\epsilon}\left(1 - \frac{1}{\epsilon}\right)L^{-1/\epsilon}\left(g(w^I)I + \frac{\partial \nu}{\partial w^I}\right) \\
&\quad - (c'(\nu(w^I)/I) + w^m)\frac{\partial \nu}{\partial w^I} - G(w^I)I - w^I g(w^I)I \\
&= \left(MRP - \frac{G(w^I)}{g(w^I)} - w^I\right)g(w^I)I + \left(MRP - c'(\nu(w^I)/I) - w^m\right)\frac{\partial \nu}{\partial w^I} \\
&= \left(MRP - \frac{w^I - w^m}{\eta} - w^I\right)g(w^I)I + \left(MRP - c'(\nu(w^I)/I) - w^m\right)\frac{\partial \nu}{\partial w^I}.
\end{aligned}$$

Recognize that the FOC for N implies

$$MRP - w^m - c'(\nu(w^I)/I) = 0,$$

so the partial derivative of profits simplifies further to

$$\partial_{w^I}\Pi(w^I, I) = \left(MRP - \frac{w^I - w^m}{\eta} - w^I\right)g(w^I)I.$$

Intuitively, the partial derivative of profits with respect to w^I is the gain in sales net of the wages paid to inframarginal and marginal workers multiplied by the marginal change in retention probability. When $\phi = 0$, this derivative is set to zero. When $\phi \in (0, 1)$ the optimal solution features $w^I > w^m$ and $\Pi(w^I, I) > \underline{\Pi}$. It must be the case (for an interior solution) that the partial derivative of profits to wages is negative, i.e.,

$$MRP < \frac{w^I - w^m}{\eta} + w^I.$$

The marginal revenue product decreases in w^I, hence it is the case that w^I is higher with worker bargaining power.

When $I = 0$, the marginal product simplifies to

$$MRP = \left(1 - \frac{1}{\epsilon}\right) P^0 N^{-1/\epsilon},$$

so that when $\underline{N}$ solves

$$\left(1 - \frac{1}{\epsilon}\right) P^0 \underline{N}^{-1/\epsilon} = w^m + c'(\underline{N}),$$

profits are

$$\underline{\Pi} = P^0 \underline{N}^{1-1/\epsilon} - c(\underline{N}/I)I - w^m \underline{N}.$$

The surplus profits from retaining incumbents is

$$\begin{aligned}
\Pi - \underline{\Pi} &= P^0((G(w^I)I + \nu(w^I))^{1-1/\epsilon} - \underline{N}^{1-1/\epsilon}) \\
&\quad - (c(\nu(w^I)/I) - c(\underline{N}/I))I - w^m(\nu(w^I) - \underline{N}) - w^I G(w^I) I \\
&= \frac{\epsilon}{\epsilon - 1}(MRPL - \underline{MRPN}) \\
&\quad - (c(\nu(w^I)/I) - c(\underline{N}/I))I - w^m(\nu(w^I) - \underline{N}) - w^I G(w^I) I
\end{aligned}$$

Re-arrange the bargaining FOC to acquire

$$\frac{w^I - w^m}{\eta} + w^I - MRP = \frac{\phi}{1-\phi} \frac{1}{g(w^I)I} \frac{\Pi(\cdot) - \underline{\Pi}}{w^I - w^m},$$

i.e., equation (20) stated in the main text.

A-1.3.2 Comparative Statics

In this section, we partially characterize the comparative statics with respect to the number of incumbents. When worker bargaining power is sufficiently low, wages will increase after an incumbent death, and greater worker bargaining power tends to reduce how much wages increase. If hiring costs are zero, then incumbent exits do not change wages. Lemma

A-1.1 derives the system of equations characterizing the equilibrium response to an incumbent death while Proposition A-1.1 signs the wage response.

Lemma A-1.1. *The responses of wages and hiring to a change in the number of incumbents satisfy the system of equations*

$$\frac{dMRP}{dI} = c''\left(\frac{N}{I}\right) I^{-1}\left(\frac{dN}{dI} - \frac{N}{I}\right) \tag{7}$$

$$\frac{dMRP}{dI} = \frac{1+\eta}{\eta}\frac{dw^I}{dI} - \frac{d\mathcal{B}}{dI} \tag{8}$$

$$\mathcal{B} \equiv \frac{\phi}{1-\phi}\frac{1}{g(w^I)I}\frac{\Pi(\cdot)-\underline{\Pi}}{w^I - w^m} \tag{9}$$

$$\frac{d\mathcal{B}}{dI} = \mathcal{B}\left(\frac{1}{\Pi(w^I, I) - \underline{\Pi}}\frac{d\Pi}{dI} - \eta\frac{1}{w^I - w^m}\frac{dw^I}{dI}\right) \tag{10}$$

$$\frac{dMRP}{dI} = -\frac{1}{\epsilon}MRP\frac{dL}{dI}\frac{1}{L} \tag{11}$$

$$\frac{dL}{dI} = \frac{dN}{dI} + Ig(w^I)\frac{dw^I}{dI} + G(w^I). \tag{12}$$

Proof. Equilibrium is characterized by the conditions

$$MRP = \left(1 - \frac{1}{\epsilon}\right) P^0 L^{-1/\epsilon}$$

$$MRP = w^m + c'\left(\frac{N}{I}\right)$$

$$MRP = \frac{w^I - w^m}{\eta} + w^I - \frac{\phi}{1-\phi}\frac{1}{g(w^I)I}\frac{\Pi(\cdot)-\underline{\Pi}}{w^I - w^m}.$$

The derivative of MRP w.r.t. I is

$$\begin{aligned}\frac{dMRP}{dI} &= -\frac{1}{\epsilon}\left(1 - \frac{1}{\epsilon}\right) P^0 L^{-1/\epsilon - 1}\frac{dL}{dI}\\ &= -\frac{1}{\epsilon}MRP\frac{dL}{dI}\frac{1}{L}\\ \frac{dL}{dI} &= \frac{dN}{dI} + Ig(w^I)\frac{dw^I}{dI} + G(w^I).\end{aligned}$$

Total differentiation of the FOCs implies

$$\frac{dMRP}{dI} = c''\left(\frac{N}{I}\right) I^{-1} \left(\frac{dN}{dI} - \frac{N}{I}\right)$$
$$\frac{dMRP}{dI} = \frac{1+\eta}{\eta}\frac{dw^I}{dI} - \frac{d\mathcal{B}}{dI},$$

where

$$\frac{d\mathcal{B}}{dI} = \frac{\phi}{1-\phi}\frac{1}{g(w^I)I(w^I-w^m)}\left(\frac{d\Pi}{dI} - \frac{\Pi(\cdot)-\underline{\Pi}}{g(w^I)I(w^I-w^m)}\left(g'(w^I)I(w^I-w^m)+g(w^I)I\right)\frac{dw^I}{dI}\right)$$
$$= \frac{\phi}{1-\phi}\frac{1}{g(w^I)I(w^I-w^m)}\left(\frac{d\Pi}{dI} - \frac{\Pi(\cdot)-\underline{\Pi}}{(w^I-w^m)}\left(\frac{g'(w^I)}{g(w^I)}(w^I-w^m)+1\right)\frac{dw^I}{dI}\right).$$

Recognize that

$$g'(w^I) = \frac{1}{\overline{w}-w^m}\eta\left(1-\frac{1}{\eta}\right)(G(w^I))^{-1/\eta}g(w^I)$$
$$\frac{g'(w^I)}{g(w^I)} = \frac{1}{\overline{w}-w^m}\eta\left(1-\frac{1}{\eta}\right)(G(w^I))^{-1/\eta}$$
$$= \frac{1}{\overline{w}-w^m}\eta\left(1-\frac{1}{\eta}\right)\left(\frac{w^I-w^m}{\overline{w}-w^m}\right)^{-1}$$
$$= \frac{\eta-1}{w^I-w^m}.$$

It follows that

$$\frac{d\mathcal{B}}{dI} = \frac{\phi}{1-\phi}\frac{1}{g(w^I)I}\frac{1}{w^I-w^m}\left(\frac{d\Pi}{dI} - \frac{\Pi(\cdot)-\underline{\Pi}}{w^I-w^m}(\eta-1+1)\frac{dw^I}{dI}\right)$$
$$= \frac{\phi}{1-\phi}\frac{1}{g(w^I)I}\frac{1}{w^I-w^m}\frac{d\Pi}{dI} - \frac{\eta}{w^I-w^m}\mathcal{B}\frac{dw^I}{dI}.$$

Use the definition of $\mathcal{B}$ to derive (10). □

Proposition A-1.1. *Suppose the hiring cost function $c(N/I)$ is strictly convex.*

(i) MRP strictly decreases with I.
(ii) If ϕ is sufficiently small, then wages strictly decrease with I.
(iii) If ϕ is sufficiently small, then positive worker bargaining power ($\phi > 0$) reduces how much wages increase after an incumbent death given the same $\frac{dMRP}{dI}$.

Proof. By the envelope theorem, profits increase with the number of incumbents. Conjecture $\frac{dMRP}{dI} > 0$. This implies $\frac{dN}{dI} > 0$ and $\frac{dw^I}{dI} > 0$. This leads to a contradiction as argued in the proof of Proposition A-1.1 when the hiring cost function is strictly convex. We may also rule out the zero derivative case by contradiction due to the strict convexity of $c(\cdot)$. If the derivative was zero, then $\frac{dN}{dI} = \frac{N}{I} > 0$ and $\frac{dw^I}{dI} > 0$ (by inspection and positivity of $\frac{d\Pi}{dI}$). This would imply $\frac{dL}{dI} > 0$, contradicting the zero response of MRP. Therefore, we must have $\frac{dMRP}{dI} < 0$.

To show (ii), notice that by Proposition A-1.1 wages strictly decrease with I when $\phi = 0$. By continuity, within a neighborhood of $\phi = 0$, i.e., for sufficiently small ϕ, this result remains true. We leave a fuller characterization of the comparative static to future work.

Finally, we prove (iii). Using (ii) and the fact that profits increase with I, we know that $\frac{d\mathcal{B}}{dI} > 0$. Further, $\frac{dMRP}{dI}$ is strictly negative under strictly convex hiring costs. For the same $\frac{dMRP}{dI}$, the only way to maintain the equality in (8) when $\phi > 0$ is for $\frac{dw^I}{dI}$ to become less negative. □

A-1.4 Intensive Margin: Hours

One reason earnings may rise in response to a worker death is that firms make their incumbents work longer hours rather than pay them higher wages. To shed light on this mechanism, we extend the baseline model with an intensive margin. We begin with an analytically tractable extension to the static model, with which we can prove comparative statics, and conclude with a more realistic quantitative dynamic model. In the analytical model, we show that if it is costly for the firm to increase hours worked by incumbents, then firms will increase earnings mostly by increasing wages. In the numerical example, we estimate the model to match existing evidence on the intensive-margin elasticity of labor supply and find that a majority of the earnings response to an incumbent death is due to wage increases.

Setup

The labor force size L now represents the number of full-time equivalent (FTE) workers employed by the firm. Let 1 FTE equal ϕ hours of work. Newly hired workers can only work ϕ hours, but the firm can control the number of hours h^I worked by incumbents. Higher hours increases the size of the effective labor force, but higher hours are not a free lunch. The subsequent analytical and quantitative sections differ in exactly how higher hours affects the firm's problem.

A-1.4.1 Analytical Model

We first assume that firms must pay additional costs if incumbents work more than ϕ hours. Without loss of generality, we set $\phi = 40$ in this section. Profits are given by

$$\begin{aligned} &P^0 Q^{\frac{\epsilon-1}{\epsilon}} - c\left(\frac{N}{I}\right) I - w^m N \\ &- \left(w^I \frac{h^I}{40} + \frac{\chi}{40}\frac{1}{1+\psi}((h^I)^{1+\psi} - 40^{1+\psi})\right) G(w^I) I, \end{aligned} \tag{13}$$

where $\psi > 0$. In addition to paying incumbents a wage w^I, the firm pays additional costs that are in convex in the number of hours worked by incumbents. The subtraction of $40^{1+\psi}$ centers these costs around 40 hours of work so that a firm choosing $h^I = 40$ is not penalized. These costs could be interpreted as additional compensation demanded by incumbents in order to work more than 40 hours, i.e., an overtime premium.

The response of wages, hours, and earnings to a change in the number of incumbents are characterized by the following proposition. The proof is in Appendix A-1.5.

Proposition A-1.1. *Assume hiring costs are strictly convex, and assume χ is chosen so that the firm sets $h^I = 40$ in equilibrium.*

(i) If $\psi > 1$, then $\frac{dw^I}{dI} < 0$, $\frac{dh^I}{dI} < 0$, and incumbent earnings decrease with I. The larger η, ψ, and χ are, the more the response is along the wage dimension.
(ii) If $\psi = 1$, then $\frac{dw^I}{dI} = 0$, $\frac{dh^I}{dI} < 0$, and incumbent earnings decrease with I.
(iii) If $\psi < 1$ and $\eta(1-\psi) < \psi$, then $\frac{dw^I}{dI} > 0$, $\frac{dh^I}{dI} < 0$, and incumbent earnings decrease with I.
(iv) If $\psi < 1$, $\eta(1-\psi) > \psi$, and $\eta > (1-\psi)^{-1}$, then $\frac{dw^I}{dI} < 0$, $\frac{dh^I}{dI} > 0$, and incumbent earnings increase with I.

To summarize, when the convexity of costs from hours is sufficiently large, wages, hours, and earnings will all increase in response to an incumbent death. This case is also the only one in which the earnings and wage response have the same sign. The more costly it is for h^I to deviate from 40, the more wages will change compared to hours. In the subsequent quantitative model, similar results will hold.

A-1.4.2 Quantitative Model

Setup and Estimation

Specifying the trade-off in (13) as additional costs to the firm renders the model analytically tractable but misses an additional trade-off that h^I may affect the probability of retention.

Define

$$r(w^I, h^I) = (1-\tau)w^I - \frac{\chi}{1+\psi}((h^I)^{1+\psi} - \phi^{1+\psi}) \tag{14}$$

to be an incumbent's "reservation earnings level", where τ is the effective tax rate, w^I is now interpreted as a worker's earnings rather than wage, and the parameters χ and ψ capture a worker's disutility from labor. The disutility is zero when hours equal the steady-state level. We include labor income taxes so that we can estimate the model using quasi-experimental evidence from tax changes on labor supply elasticities. Incumbents receive offers at other firms drawn from the distribution:

$$G(\omega) = \left(\frac{\frac{\omega}{1-\tau} - w^m}{\overline{w} - w^m}\right)^{\eta}. \tag{15}$$

The division of ω by $1-\tau$ indicates that ω is the pre-tax level of earnings and that incumbents make decisions based on the post-tax level. Unlike before, incumbents accept any offer if $\omega \geq r(w^I, h^I)$ rather than $\omega \geq (1-\tau)w^I$.

Equilibrium is now characterized by the profit function

$$\Pi(I, w^I, h^I) = P^0 Q^{\frac{\epsilon-1}{\epsilon}} - c\left(\frac{N}{I}\right) I - w^m N - w^I G(r(w^I, h^I))I$$
$$Q = T\left(N + \frac{h^I}{\phi} G(r(w^I, h^I))I\right),$$

and the four following equilibrium conditions.

$$MRP_t + \beta V'(I_{t+1}) = \frac{\epsilon - 1}{\epsilon} P_0 T^{\frac{\epsilon-1}{\epsilon}} \left(N_t + \frac{h_t^I}{\phi} G(r(w_t^I, h_t^I)) I_t \right)^{-1/\epsilon}$$

$$MRP_t + \beta V'(I_{t+1}) = w^m - c' \left(\frac{N_t}{I_t} \right)$$

$$MRP_t + \beta V'(I_{t+1}) = \left(\frac{h_t^I}{\phi} \right)^{-1} \left(\frac{(w_t^I - \frac{\chi}{1+\psi}(h_t^I)^{1+\psi}) - (w^m - \frac{\chi}{1+\psi}\phi^{1+\psi})}{\eta} + w_t^I \right)$$

$$MRP_t + \beta V'(I_{t+1}) = w_t^I \left(\frac{h_t^I}{\phi} \right)^{-1} \frac{\frac{\eta\chi}{1+\psi}(h_t^I)^{1+\psi}}{\frac{\eta\chi}{1+\psi}(h_t^I)^{1+\psi} - ((w_t^I - \frac{\chi}{1+\psi}(h_t^I)^{1+\psi}) - (w^m - \frac{\chi}{1+\psi}\phi^{1+\psi}))}$$

To estimate χ and ψ, we target $h^I = 40$ before the incumbent shock and an intensive-margin Hicksian elasticity of 0.33 following Chetty et al. (2013). Since our model is dynamic, the Hicksian elasticity is the appropriate choice when using a steady-state tax change. The intensive-margin elasticity is calculated by computing the elasticity of hours to a permanent decrease in the effective tax rate by 1%, as in Chetty et al. (2013).

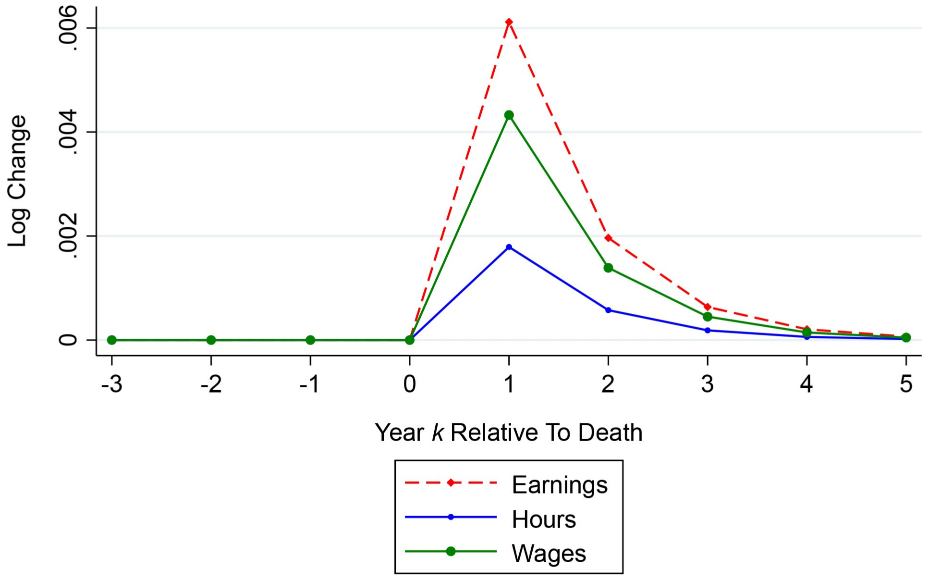
We calibrate the remaining parameters. We set $\tau = 0.15$ so that the average labor income tax rate is 15% and $\phi = 31.55$ so that there is no penalty for choosing the steady-state level of hours.

Results

Table A-4.14 reports the estimated parameters. Figure A.1 plots the log change in earnings relative to steady state and decomposes the change into wages and hours. The figure shows that the majority of the earnings response can be attributed to wages, although hours do change a nontrivial amount. For example, the wage change explains 71.7% of the log earnings change in the first year after an incumbent death.

For completeness, we also reproduce the empirical event studies and calculate measures of replacement costs. Figures A.2 - A.4 shows the event studies. Figure A.4 also shows the model-implied earnings path if either hours did not move (“Model Wages”) or wages did not move (“Model Hours”) after an incumbent death.

Figure A.1: Log Change in Earnings, Wages, and Hours in Response to Worker Death



Source: Own calculations.

A-1.5 Proofs

A-1.5.1 Proof of Proposition A-1.1

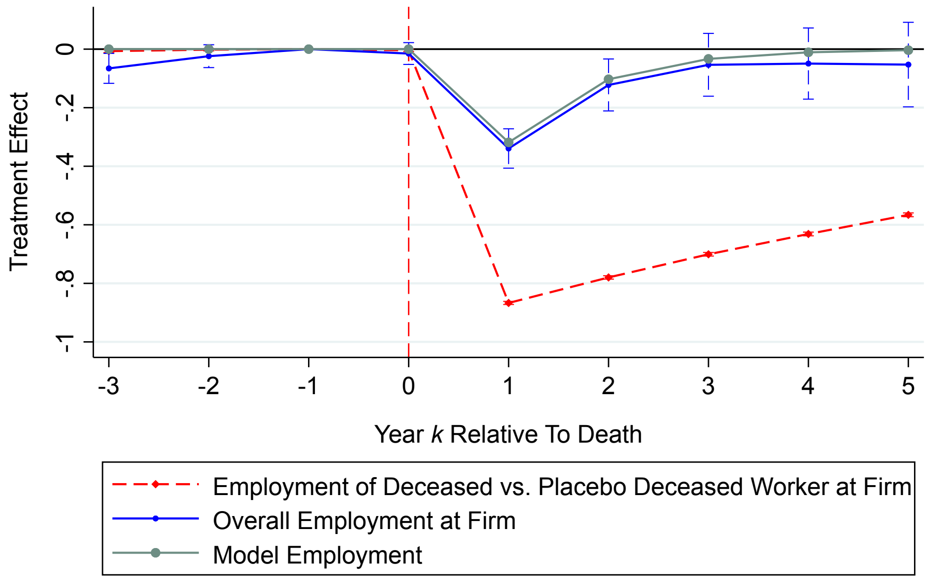
Proof. To obtain (23), we implicitly differentiate the definition of MRP and the two FOCs (7) and (8). The derivatives of MRP and L are given by:

$$\begin{aligned} \frac{dMRP}{dI} &= -\frac{1}{\epsilon}\left(\frac{\epsilon-1}{\epsilon}\right)P^0T^{1-1/\epsilon}L^{-1/\epsilon-1}\frac{dL}{dI} \\ &= -\frac{1}{\epsilon}MRP\frac{dL}{dI}\frac{1}{L} \\ \frac{dL}{dI} &= \frac{dN}{dI} + Ig(w^I)\frac{dw^I}{dI} + G(w^I) \\ &= \frac{dN}{dI} + I\eta G(w^I)\frac{1}{w^I - w^m}\frac{dw^I}{dI} + G(w^I). \end{aligned}$$

We then use these results to differentiate the two FOCs and simplify.

Consider claim (i). Suppose hiring costs are strictly convex. We prove that $\frac{dMRP}{dI} < 0$ by

Figure A.2: Labor Supply Shock and Employment Effects Of Worker Death



Source: Own calculations.

contradiction. Suppose not.

First consider the case of $\frac{dMRP}{dI} > 0$. Then $\frac{dL}{dI} < 0$ from the derivative of MRP, $\frac{dw^I}{dI} > 0$ from the wage FOC, and $\frac{dN}{dI} > 0$ from the hiring FOC, as $c''(\cdot) > 0$. The latter two signs, however, imply $\frac{dL}{dI} > 0$, a contradiction.

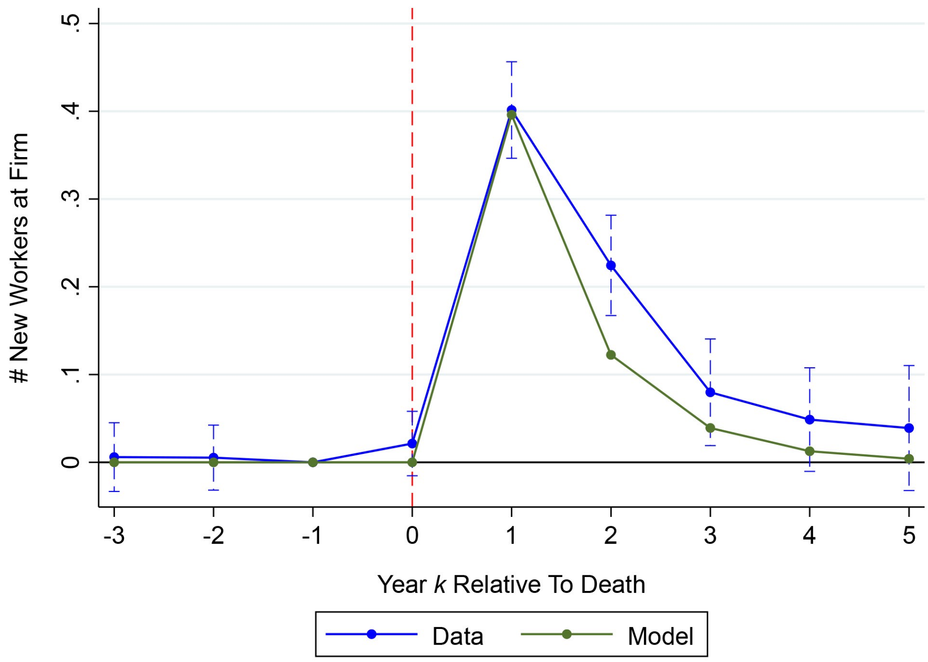
Now consider the case of $\frac{dMRP}{dI} = 0$. Then $\frac{dw^I}{dI} = 0$, and $\frac{dN}{dI} = N/I$, as hiring costs are strictly convex. It follows that $\frac{dL}{dI} > 0$, but this sign contradicts a zero marginal product response.

To finish claim (i), we proceed by contraposition and suppose hiring costs are linear (it is assumed $c(\cdot)$ is weakly convex). Then $c''(\cdot) = 0$, so $\frac{dMRP}{dI} = 0$. This implies $\frac{dw^I}{dI} = 0$. The former equality completes the proof.

Claim (ii) follows from the previous argument. Linear hiring costs imply $\frac{dMRP}{dI} = 0$, hence $\frac{dL}{dI} = 0$. For this latter equality to hold, $\frac{dN}{dI} < 0$.

Claim (iii) follows from Claim (i)'s argument. In particular, when hiring costs are strictly convex, $\frac{dMRP}{dI} < 0$ implies the result. When hiring costs are linear, $\frac{dN}{dI} < 0$.

Figure A.3: Effect of Worker Death on Hiring



Source: Own calculations.

The hypothesis of Claim (iv) means that

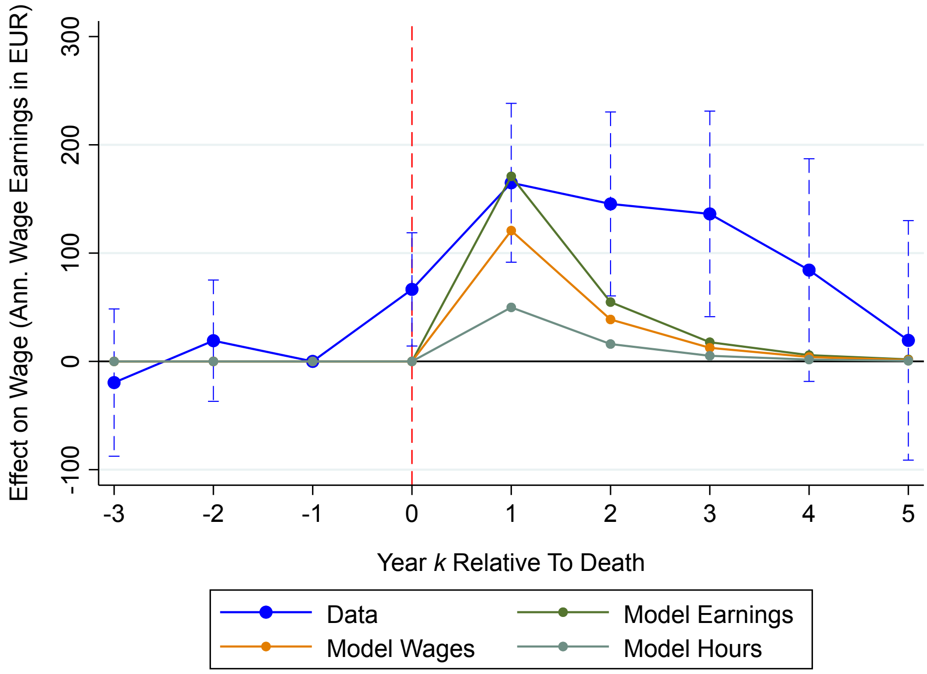
$$\frac{dMRP}{dI} = \frac{c''(\frac{N}{I})}{I}\frac{dN}{dI}.$$

The conclusion of Claim (iv) follows from Claim (i). □

A-1.5.2 Proofs for Model with Intensive Margin

The equilibrium conditions are

Figure A.4: Earnings, Wages and Hours Responses



Source: Own calculations.

$$MRP = w^m + c'\left(\frac{N}{I}\right) \tag{16}$$

$$MRP = w^I + \frac{w^I - w^m}{\eta} + \frac{\chi}{1+\psi}((h^I)^\psi - 40^{1+\psi}/h^I) \tag{17}$$

$$MRP = w^I + \chi(h^I)^\psi \tag{18}$$

$$\frac{w^I - w^m}{\eta} = \frac{\chi}{h^I}\frac{1}{1+\psi}\left(\psi(h^I)^{1+\psi} + 40^{1+\psi}\right) \tag{19}$$

$$\begin{aligned} MRP &= \frac{P(L)L}{L} \\ &= \left(\frac{\epsilon-1}{\epsilon}\right) P^0 T^{1-1/epsilon} L^{-1/epsilon} \end{aligned} \tag{20}$$

$$P(L) = P^0 L^{-1/epsilon} \tag{21}$$

$$L = N + G(w^I)I\frac{h^I}{40}. \tag{22}$$

To obtain the comparative statics in Proposition A-1.1 implicitly differentiate these conditions to obtain the following lemma.

Lemma A-1.1. *The equilibrium response to an exogenous shock in I is characterized by the following system of equations:*

$$\frac{dMRP}{dI} = \frac{c''(\frac{N}{I})}{I}\left(\frac{dN}{dI} - \frac{N}{I}\right) \tag{23}$$

$$\frac{dMRP}{dI} = \frac{1+\eta}{\eta}\frac{dw}{dI} + \chi\frac{\psi}{1+\psi}(h^I)^{\psi-1}\frac{dh^I}{dI} + \chi\frac{1}{1+\psi}40^{1+\psi}(h^I)^{-2}\frac{dh^I}{dI} \tag{24}$$

$$\frac{dMRP}{dI} = \frac{dw^I}{dI} + \chi\psi(h^I)^{\psi-1}\frac{dh^I}{dI} \tag{25}$$

$$\frac{dMRP}{dI} = -\frac{1}{\epsilon}MRP\frac{1}{L}\frac{dL}{dI} \tag{26}$$

$$\frac{dL}{dI} = \frac{dN}{dI} + G(w^I)\frac{h^I}{40} + g(w^I)I\frac{h^I}{40}\frac{dw^I}{dI} + G(w^I)I\frac{1}{40}\frac{dh^I}{dI}. \tag{27}$$

(28)

Further, the wage and hours response are related by

$$\frac{dw^I}{dI} = \frac{\eta\chi}{1+\psi}40^{1+\psi}\left(\psi^2\left(\frac{h^I}{40}\right)^{1+\psi} - 1\right)(h^I)^{-2}\frac{dh^I}{dI}. \tag{29}$$

As a corollary, we can unambiguously sign the wage and hours responses when any level of hours incurs convex costs.

Proposition A-1.1. *Suppose the costs from changing hours was not centered at 40, i.e., the firm pays $(\chi/40)(1+\psi)^{-1}(h^I)^{1+\psi}$ per retained incumbent rather than $(\chi/40)(1+\psi)^{-1}((h^I)^{1+\psi} - 40^{1+\psi})$. Then $\frac{dw^I}{dI} < 0$ and $\frac{dh^I}{dI} < 0$.*

We first prove Lemma A-1.1 and Proposition A-1.1. We then conclude this subsection with the proof of Proposition A-1.1.

Proof of Lemma A-1.1. Implicitly differentiate the FOCs in (16) - (22) to obtain (23) - (27).

To derive (28), recognize that

$$\frac{dw^I}{dI} + \chi\psi(h^I)^{\psi-1}\frac{dh^I}{dI}$$
$$= \frac{1+\eta}{\eta}\frac{dw}{dI} + \chi\frac{\psi}{1+\psi}(h^I)^{\psi-1}\frac{dh^I}{dI} + \chi\frac{1}{1+\psi}40^{1+\psi}(h^I)^{-2}\frac{dh^I}{dI}.$$

Rearrange.

$$\frac{1}{\eta}\frac{dw^I}{dI} = \left(\chi\psi\frac{\psi}{1+\psi}(h^I)^{1+\psi} - \chi\frac{1}{1+\psi}40^{1+\psi}\right)(h^I)^{-2}\frac{dh^I}{dI}$$
$$\frac{dw^I}{dI} = \frac{\eta\chi}{1+\psi}40^{1+\psi}\left(\psi^2\left(\frac{h^I}{40}\right)^{1+\psi} - 1\right)(h^I)^{-2}\frac{dh^I}{dI}.$$

□

Proof of Proposition A-1.1. In every equation of (23) - (27), replace $40^{1+\psi}$ by 0. Then (28) becomes

$$\frac{dw^I}{dI} = \frac{\eta\chi}{1+\psi}\psi^2(h^I)^{1+\psi}(h^I)^{-2}\frac{dh^I}{dI}, \tag{30}$$

and since $\psi > 0$, the sign of the wage and hours responses must be the same.

We claim that $\frac{dMRP}{dI} < 0$. Suppose not. First consider the case of a positive derivative. Then $\frac{dN}{dI} > 0$ and $\frac{dL}{dI} < 0$ by (27), (26), and strict convexity of $c(N/I)$. Since the sign of the wage and hours responses are the same, (25) implies $\frac{dw}{dI} > 0$ and $\frac{dh^I}{dI} > 0$. But in that case, (27) implies $\frac{dL}{dI} > 0$ because every term is strictly positive, a contradiction. Now consider the case of a zero derivative. Then

$$\frac{dN}{dI} = \frac{N}{I}, \quad \frac{dw^I}{dI} = \frac{dh}{dI} = 0$$

from (23), (24), and (28). This implies $\frac{dL}{dI} > 0$, which contradicts $\frac{dMRP}{dI} = 0$.

Since $\frac{dMRP}{dI} < 0$, $\frac{dL}{dI} > 0$. As before, the signs of the wage and hours responses must be the same, hence $\frac{dw}{dI} < 0$, and $\frac{dh}{dI} < 0$. The sign of hiring is ambiguous unless we ignore the scale effect so that (23) becomes

$$\frac{dMRP}{dI} = \frac{c''(\frac{N}{I})}{I}\frac{dN}{dI}.$$

In this case, $\frac{dN}{dI} < 0$. Note that these signs are possible because there is one term in $\frac{dL}{dI}$ which is always positive. □

Proof of Proposition A-1.1. We first prove the results on the wage and hours response. The earnings results follow quickly as a consequence.

Suppose hours have been calibrated to 40 in some steady state by varying χ.

Then

$$\frac{dw^I}{dI} = \frac{\eta\chi}{1+\psi}40^{\psi-1}(\psi^2-1)\frac{dh^I}{dI} = \eta\chi 40^{\psi-1}(\psi-1)\frac{dh^I}{dI}. \quad (31)$$

The sign of the wage response depends on ψ. If $\psi > 1$, then the wage and earnings response are identical. The argument offered in the proof of Proposition A-1.1 proves that $\frac{dMRP}{dI} < 0$, $\frac{dw^I}{dI} < 0$, and $\frac{dh^I}{dI} < 0$. From (31), the larger η, ψ, and χ are, the larger the wage derivative is relative to the hours derivative. If $\psi = 1$, then the wage response is zero, hence the response of earnings must entirely be along the hours dimension.

Now suppose $\psi < 1$. Then the wage response takes the opposite sign of the hours response. The derivative of the third FOC w.r.t. h^I implies

$$\begin{aligned}\frac{dMRP}{dI} &= \left(\eta\chi 40^{\psi-1}(\psi-1) + \chi\psi(40)^{\psi-1}\right)\frac{dh^I}{dI} \\ &= \chi 40^{\psi-1}\left(\eta(\psi-1)+\psi\right)\frac{dh^I}{dI} \\ &= \chi\psi 40^{\psi-2}(\psi-\eta(1-\psi))\frac{dh^I}{dI}.\end{aligned}$$

The sign in this case depends on η. Recall that $\psi < 1$. If η is close to zero or ψ is close to 1, then the hours response takes the same sign as $\frac{dMRP}{dI}$. If η is large or ψ is close to 1, then the hours response takes the opposite sign.

To determine the sign of $\frac{dMRP}{dI}$, consider $\frac{dL}{dI}$. We have

$$
\begin{aligned}
\frac{dL}{dI} &= \frac{dN}{dI} + G(w^I) + g(w^I)I\frac{dw^I}{dI} + G(w^I)I\frac{1}{40}\frac{dh^I}{dI} \\
&= \frac{dN}{dI} + G(w^I) + \left(g(w^I)\eta\chi 40^{\psi-1}(\psi-1) + G(w^I)\frac{1}{40}\right) I\frac{dh^I}{dI}.
\end{aligned}
$$

Recall that

$$
g(w^I) = \eta G(w^I)\frac{1}{w^I - w^m}
$$

and also that

$$
w^I - w^m = \frac{\eta\chi}{h^I}\frac{1}{1+\psi}\left(\psi(h^I)^{1+\psi} + 40^{1+\psi}\right) = \eta\chi\frac{1}{1+\psi}(\psi+1)40^{\psi} = \eta\chi 40^{\psi}.
$$

It follows that

$$
\begin{aligned}
\frac{dL}{dI} &= \frac{dN}{dI} + G(w^I) + \left(1 - \eta^2\chi 40^{\psi}(1-\psi)\frac{1}{w^I - w^m}\right)\frac{1}{40}G(w^I)I\frac{dh^I}{dI} \\
&= \frac{dN}{dI} + G(w^I) + (1 - \eta(1-\psi))\frac{1}{40}G(w^I)I\frac{dh^I}{dI}
\end{aligned}
$$

Consider case (iii), in which we suppose $\eta(1-\psi) < \psi$. We prove $\frac{dMRP}{dI} < 0$ by contradiction. First suppose $\frac{dMRP}{dI} > 0$. Our parameter assumptions imply $\frac{dh^I}{dI} > 0$. Further, (23) implies $\frac{dN}{dI} > 0$. Then

$$
1 - \eta(1-\psi) > 1 - \psi > 0,
$$

with the latter inequality following from the fact that $\psi < 1$. Then $\frac{dL}{dI} > 0$, but that contradicts $\frac{dMRP}{dI} > 0$. Now consider $\frac{dMRP}{dI} = 0$. Then $\frac{dN}{dI} = N/I$, and $\frac{dh^I}{dI} = 0$, hence $\frac{dL}{dI} > 0$, a contradiction. Thus, $\frac{dMRP}{dI} < 0$, $\frac{dh^I}{dI} < 0$, and $\frac{dw^I}{dI} > 0$.

Finally, consider case (iv), in which we suppose $\eta(1-\psi) > \psi$ and $\eta > (1-\psi)^{-1}$. Proof by contradiction using similar arguments as before shows that $\frac{dMRP}{dI} < 0$. Under these parameter restrictions, $\frac{dh^I}{dI} > 0$, hence $\frac{dw^I}{dI} < 0$.

Now return to the earnings response. Using (31), the earnings response can be written as

$$\begin{aligned}\frac{dw^I h^I}{dI} &= \frac{dw^I}{dI}h^I + w^I\frac{dh^I}{dI}\\&= \eta\chi 40^{\psi-1}(\psi-1)\frac{dh^I}{dI}h^I + w^I\frac{dh^I}{dI}\\&= \left(\eta\chi(\psi-1)40^{\psi-1}h^I + w^I\right)\frac{dh^I}{dI}.\end{aligned}$$

Since h^I is calibrated to 40,

$$\frac{dw^I h^I}{dI} = \left(\eta\chi(\psi-1)40^{\psi} + w^I\right)\frac{dh^I}{dI}.$$

Equilibrium condition (19) and $h^I = 40$ implies

$$w^I = w^m + \eta\chi 40^{\psi},$$

hence

$$\begin{aligned}\eta\chi(\psi-1)40^{\psi} + w^I &= \eta\chi(\psi-1)40^{\psi} + w^m + \eta\chi 40^{\psi}\\&= \eta\chi\psi 40^{\psi} + w^m\\&> 0\end{aligned}$$

since $\psi > 0$. Therefore, the earnings response takes the same sign as the hours responses. □

A-2 Worker Exits in Models with Multi-Worker Firms and Intrafirm Bargaining

This section discusses the link between the effects of worker exits on worker and firm outcomes and frictions in replacing workers in models with multi-worker firms and intrafirm bargaining: first, in the canonical model for wage determination within firms developed by Stole/Zwiebel (1996a,b) in which workers cannot be replaced in the short run; second, in a model in which incumbent workers can be replaced by a pool of outside workers which nests the competitive labor market as a corner case when the pool of outsiders is large (De Fontenay/Gans, 2003); third, in a search-and-matching model with heterogeneous labor and wage bargaining following Cahuc/Marque/Wasmer (2008) (see also Wolinsky (2000); Elsby/Michaels (2013); Acemoglu/Hawkins (2014); Hawkins (2015) for intrafirm bargaining in a search-and-matching framework).

A-2.1 Incumbent Worker Wage Effects With Homogenous Labor and No Replacement

We illustrate how worker exits affect the remaining incumbent workers' wages in the canonical model for wage determination inside firms by Stole and Zwiebel (1996a,b), which consists of a multilateral bargaining setup that generalizes Nash bargaining. A key assumption is that workers cannot be replaced on the external labor market in the short run, for instance because they have high levels of firm-specific human capital. A more realistic interpretation of this assumption is the idea that human capital specificity or turnover costs lead to rents arising from continuing the employment relationship, thus creating a bilateral monopoly between the firm and each worker.[1] In the Stole and Zwiebel framework, labor contracts are assumed to be nonbinding. This assumption follows a long line of research on holdup and the theory of the firm (see, e.g., Grossman/Hart, 1986), which posits that it is costly to write or enforce complete contracts and that contracts can be renegotiated. We first describe the main features of the Stole and Zwiebel framework and

[1] Alternatively, incumbent workers could be hard to replace if firms have better information on incumbent workers (see models in Greenwald, 1986 and Waldman, 1984). The evidence is mixed with some studies finding support for such information asymmetry (see, e.g., Gibbons/Katz, 1991, and Kahn, 2013) while others are more consistent with a model in which employer learning about worker ability is public information (Farber/Gibbons 1996; Altonji/Pierret 2001 and Schönberg, 2007). Felli/Harris (1996) provide a model that shows how information about match quality with a given employer can be interpreted as firm-specific human capital.

then illustrate wage effects in this setup. In a simple setting with homogenous labor, worker exits raise coworker wages when firms' production functions have decreasing returns to scale and lower wages when returns to scale are increasing.

Consider a firm negotiating with N identical, specialized workers who cannot be replaced in the short run. Output is produced according to a production function $F(N):\mathbb{N}\rightarrow\mathbb{R}_{+}$. The operator Δ denotes first differences so that $\Delta F(N)=F(N)-F(N-1)$ captures the increase in output when producing with N rather than $N-1$ workers. The firm's profits are given by $\tilde{\pi}(N)=F(N)-\tilde{w}(N)N$ where $\tilde{w}(N)$ denotes the wage that each worker receives when a total of N workers are employed by the firm.

Wages are determined in pairwise negotiations between the firm and each worker in which the surplus is split equally.[2] When negotiations between a worker and the firm break down, the worker receives an outside wage of $\underline{w}$ and the firm continues the negotiations with the remaining workers. For each pairwise negotiation, the payoffs correspond to the Nash bargaining solution with equal bargaining power.[3] Labor contracts are assumed to be non-binding in the sense that no long-term contracts can be written.[4] The following analysis focuses on *stable* outcomes which are defined as wage profiles such that neither an individual worker nor the firm can improve their wage or the profit, respectively, by pairwise renegotiation.

Splitting the surplus in the pairwise negotiation requires that the firm's change in profit from retaining a worker equals the worker's wage above her outside wage $\underline{w}$:

$$\underbrace{\tilde{\pi}(N)-\tilde{\pi}(N-1)}_{\text{Firm's surplus}}=\underbrace{\tilde{w}(N)-\underline{w}}_{\text{Worker's surplus}}. \tag{1}$$

In the setup with only one worker, the firm's surplus is $\Delta F(1)-\tilde{w}(1)$, the worker's surplus is $\tilde{w}(1)-\underline{w}$ and the total surplus $\Delta F(1)-\underline{w}$ leading to a wage of:

$$\tilde{w}(1)=\underline{w}+\frac{1}{2}(\Delta F(1)-\underline{w})=\frac{1}{2}(\Delta F(1)+\underline{w}). \tag{2}$$

This wage will only be feasible if $\Delta F(1)\geq\underline{w}$ as the employee otherwise prefers her outside

2 The setup can be easily extended to situations with asymmetric bargaining power as in section A-2.3.
3 Stole and Zwiebel prove that this solution corresponds to the subgame-perfect equilibrium of an extensive-form game in which the firm negotiates with the workers sequentially. Recently, Brügemann/Gautier/Menzio (2019) proved that this solution does not correspond to the Shapley value of a corresponding cooperative game and propose an alternative extensive-form game between a firm and its workers, labeled Rolodex Game, that does correspond to the Shapley value.
4 In contrast, when binding long-term contracts can be written, the firm can pay workers their outside wage $\underline{w}$ so that profits correspond to $\pi(N)=F(N)-\underline{w}N$.

wage.

In a setup with two workers to be employed by the firm, the firm's outside option when negotiations with one of the workers break down are affected by $\tilde{w}(1)$. This is the key difference to models without multilateral intra-firm bargaining. Specifically, when retaining a second worker the firm's profit will be $\tilde{\pi}(2) = F(2) - 2 \cdot \tilde{w}(2)$; when negotiations with one worker break down the profit will be $\tilde{\pi}(1) = F(1) - \tilde{w}(1)$ so that the splitting rule requires that:

$$\Delta F(2) - \tilde{w}(2) + [\tilde{w}(1) - \tilde{w}(2)] = \tilde{w}(2) - \underline{w}. \tag{3}$$

As a consequence, the wage at the two-worker firm then corresponds to:

$$\tilde{w}(2) = \frac{1}{3}\Delta F(2) + \frac{1}{6}\Delta F(1) + \frac{1}{2}\underline{w}. \tag{4}$$

Importantly, the wage now not only depends on the marginal product $\Delta F(2)$ but also on the inframarginal change in output $\Delta F(1)$. A simple proof by induction leads to the following general expression for wages in a firm with N incumbent workers:[5]

$$\tilde{w}(N) = \frac{1}{N(N+1)} \sum_{i=0}^{N} i \Delta F(i) + \frac{1}{2}\underline{w}. \tag{5}$$

Intuitively, the wage corresponds to a weighted average of the marginal products integrated over the size of the firm. Marginal products that are closer to the margin of production receive a higher weight so that the marginal product of the Nth worker has a higher weight than the marginal product of the first worker. Note, though, that all workers are identical and consequently receive identical wages of $\tilde{w}(N)$.

The expression for the wage in (5) can be used to calculate how the wages of the remaining $N-1$ incumbent workers change when a worker exits the firm:

$$\underbrace{\tilde{w}(N-1) - \tilde{w}(N)}_{\text{Wage Change}} = \frac{1}{N+1}\left(\sum_{i=0}^{N-1} \underbrace{\frac{2i}{N(N-1)}\Delta F(i)}_{\substack{\text{Weighted Marginal Product} \\ \text{of } i\text{th worker}}} - \underbrace{\Delta F(N)}_{\substack{\text{Marginal Product} \\ \text{of } N\text{th worker}}} \right). \tag{6}$$

[5] See equations (2) and (3) in Stole and Zwiebel (1996). Note that this solution is only feasible if $\Delta F(i) \geq \underline{w}, \forall i \leq N$.

The wage change is proportional to the difference between the marginal product of the Nth worker, $\Delta F(N)$, and the weighted marginal products of workers 1 through $N-1$.[6] For a single-factor production function with decreasing returns to scale, $F'(N) > 0$, $F''(N) < 0$, i.e., substitutability among incumbents, the wages of remaining incumbent workers thus rise following the exit of a coworker from the firm, since $\Delta F(i) > \Delta F(N), \forall i < N$. For a constant-returns-to-scale production function, the wage effect is zero. If the production function features increasing returns to scale—implying that incumbent workers are complements to each other—the wage effect of a worker exit is negative because $\Delta F(i) < \Delta F(N), \forall i < N$. In the Cahuc/Marque/Wasmer (2008) model with heterogeneous labor, that we discuss in Appendix A-2.3, a similar logic arises with wages of substitutes rising and complements falling after a worker exit.

A-2.2 Incumbent Worker Wage Effects With Homogenous Labor and Replacement

We now illustrate wage effects in a model with a pool of workers on the external labor market from which the firm can hire as in De Fontenay/Gans (2003), which relaxes the assumption that workers cannot be replaced externally. The model nests the Stole and Zwiebel model as well as the competitive labor market as corner cases and documents that wage effects on incumbent workers are zero in labor markets with a large pool of suitable workers available on the external market. More generally, wage effects become smaller in magnitude when firms face fewer search frictions.

The setup in the previous section stressed the importance of firm-specific human capital and the irreplaceability of workers in the short run. In contrast, the setup in this section implicitly posits that occupation-or industry-specific human capital may be important but firm-specific human capital is negligible. Suppose, for instance, that when a senior bioengineer quits, a firm that hires a similar engineer with industry experience can continue the production process without much disruption but would not be able to do so if it hires a worker without any relevant experience.

Following De Fontenay/Gans (2003), there is a pool of $\bar{N}$ workers of which $N \leq \bar{N}$ insiders are employed by the firm. When negotiations with one of the insiders break down, the firm can costlessly hire one of the remaining outsiders. Letting the subscript $\bar{N} - N$ denote the number of outsiders, De Fontenay/Gans (2003) prove that the negotiated wage paid by the firm corresponds to a linear combination of the wage in the setting without replacement, $\tilde{w}(N)$, and the workers' outside wage $\underline{w}$:

[6] Note that the weights sum up to 1: $\sum_{i=0}^{N-1} \frac{2i}{N(N-1)} = 1$.

$$\tilde{w}_{\bar{N}-N}(N) = \left(\frac{N}{N+1}\right)^{\bar{N}-N} \tilde{w}(N) + \left(1 - \left(\frac{N}{N+1}\right)^{\bar{N}-N}\right) \underline{w}. \tag{7}$$

This setup nests the competitive labor market case when the number of replacement workers on the outside labor market becomes large, which results in wages paid by the firm corresponding to workers' outside wages and no rents earned by workers ($\lim_{\bar{N}\to\infty} \tilde{w}_{\bar{N}-N}(N) = \underline{w}$). It also nests the case with irreplaceable workers when no outsiders are available and $\bar{N} = N$, and the firm pays wages according to (5) as in Stole and Zwiebel.

As the worker who exited is replaced by an outsider, employment at the firm stays constant at N but the pool of outsiders is reduced by one. Based on (7), the wage change for incumbent workers when a worker exits from the firm and outsiders are available ($\bar{N} > N$) corresponds to:

$$\tilde{w}_{\bar{N}-1-N}(N) - \tilde{w}_{\bar{N}-N}(N) = \left(\frac{N}{N+1}\right)^{\bar{N}-N} \frac{1}{N} \left(\tilde{w}(N) - \underline{w}\right). \tag{8}$$

The wage change is proportional to the rents, $\tilde{w}(N) - \underline{w}$, that workers earn above their outside wage and decreases in the number of outsiders that can replace insiders, $\bar{N} - N$.

Based on (8), we can directly test two hypotheses regarding the fluidity of labor markets using our empirical design. First, a non-zero effect of a worker exit on coworker wages rejects the hypothesis that workers' wages equal their outside option, $\tilde{w}(N) = \underline{w}$, and a positive wage change indicates that workers earn a wage above their outside option. Second, a non-zero wage effect of worker exits also rejects the hypothesis that the size of the pool of replacement workers, $\bar{N} - N$, is large as $\lim_{\bar{N}\to\infty} \tilde{w}_{\bar{N}-1-N}(N) - \tilde{w}_{\bar{N}-N}(N) = 0$.

A-2.3 Incumbent Worker Wage Effects With Heterogeneous Labor and Search Frictions

Here, we illustrate the relationship between worker substitutability and wage effects of worker exits in a dynamic search-and-matching model Pissarides (2000) with intrafirm bargaining and heterogeneous labor following Cahuc/Marque/Wasmer (2008). Abandoning the assumption of homogenous labor allows for a characterization of wage effects across worker types. As in the static model with homogenous labor, the sign of the wage effect of a worker exit identifies the substitutability between different worker types inside the firm with substitutes associated with positive and complements associated with negative wage effects. Similar to the intuition in Section A-2.2, the magnitude of the wage effect is proportional to the search frictions that the firm faces.

Consider a production function $F(N_1, ..., N_n)$ with $n \geq 1$ types of labor, indexed by $i = 1, ..., n$, and let $\mathsf{N} = (N_1, ..., N_n)$ denote the vector of labor inputs. When the representative firm wants to hire a worker of type i, it posts a vacancy V_i and incurs a hiring cost of γ_i. As in standard search models, the matching function $h_i(u_i, V_i)$ is assumed to have constant returns to scale and to be increasing in each argument. Labor market tightness for worker type i is denoted by $\theta_i = V_i/u_i$ and the firm's probability of filling a vacancy for worker type i per unit of time is given by $q_i(\theta_i) = h_i(u_i, V_i)/V_i$.[7] Existing jobs are destroyed at an exogenous destruction rate of s_i. The wage of workers of type i is denoted by $w_i(\mathsf{N})$ as it can depend on the vector of labor inputs N and is determined as the result of Nash bargaining as in Stole and Zwiebel with worker's bargaining power denoted by β.

The firm's hiring decision for each worker type is determined by the solution to the following Bellman equation:

$$\Pi(\mathsf{N}) = \max_{\mathsf{V}} \left(\frac{1}{1 + r\,dt}\right) \left\{ \left[F(\mathsf{N}) - \sum_{j=1}^{n} (w_j(\mathsf{N})N_j - \gamma_j V_j) \right] dt + \Pi(\mathsf{N}^+) \right\}, \tag{9}$$

subject to the law of motion for employment

$$N_i^+ = N_i(1 - s_i\,dt) + V_i q_i\,dt, \ \forall i \in \{1, .., n\}. \tag{10}$$

Here, V denotes the vector of vacancies for each worker type and N_i^+ denotes the employment of worker type i at date $t + dt$. In the steady state, the solution to the firm's problem for hiring workers of type i can be characterized as follows:

$$\underbrace{\frac{F_i(\mathsf{N}) - w_i(\mathsf{N}) - \sum_{j=1}^{n} N_j \frac{\partial w_j(\mathsf{N})}{\partial N_i}}{r + s_i}}_{\text{Marginal Benefit of Employment of Type } i} = \underbrace{\frac{\gamma_i}{q_i}}_{\text{Marginal Cost of Hiring}} . \tag{11}$$

This expression can be rearranged to assess the relationship between the marginal product of workers of type i and labor costs:

[7] The firm takes the filling rate $q_i(\theta_i)$ as given, i.e., the firm should be thought of as small relative to the market.

$$\underbrace{F_i(\mathsf{N})}_{\text{Marginal Product}} = \underbrace{w_i(\mathsf{N})}_{\text{Wage}} + \underbrace{\frac{\gamma_i(r+s_i)}{q_i}}_{\text{Turnover Costs}} + \underbrace{\sum_{j=1}^{n} N_j \frac{\partial w_j(\mathsf{N})}{\partial N_i}}_{\text{Employment Wage Effect}}. \tag{12}$$

The last term is absent in standard search models without intra-firm bargaining. For constant-returns-to-scale production functions, the employment wage effect is irrelevant (Cahuc/Wasmer, 2001). For decreasing-returns-to-scale production functions, however, the employment wage effect is negative. This moderates the effect of product demand shocks on wages as firms that increase their employment can lower wages. Previous research designs used calibrations or simulations to gauge the importance of the employment wage effect. Based on our research design, we can directly estimate the effect of shocks to employment on the wages of the remaining workers and thereby provide an estimate of employment wage effects.

As in Stole and Zwiebel, wages are determined by a Nash bargaining rule:

$$\beta \underbrace{\frac{\partial \Pi(\mathsf{N})}{\partial N_i}}_{\substack{\text{Firm's}\\ \text{Marginal Profit}}} = (1-\beta) \underbrace{\frac{w_i(N) - rU_i}{r+s_i}}_{\substack{\text{Worker's}\\ \text{Surplus}}}, \tag{13}$$

where U_i denotes the expected value of being unemployed, or the reservation utility, of a worker of type i and β denotes worker's bargaining power.[8] Cahuc/Marque/Wasmer (2008) derive the wage $w_i(\mathsf{N})$ earned by workers of type i:

$$w_i(\mathsf{N}) = (1-\beta) rU_i + \int_0^1 z^{\frac{1-\beta}{\beta}} F_i(\mathsf{N}z)\, dz. \tag{14}$$

The wage expression has an intuitive interpretation similar to the Stole and Zwiebel formula in (5). A worker's wage corresponds to the sum of a term proportional to the worker's outside option, rU_i or the flow value of unemployment, and the worker type's marginal product integrated over the total employment at the firm. The weights, $z^{\frac{1-\beta}{\beta}}$, depend on the worker's bargaining power β and are linearly increasing, as in the simple static model in (5), when $\beta = \frac{1}{2}$.

Equation (14) demonstrates that the sign of the effect of a change in the employment of worker type j at the firm on the wages of workers of type i at the firm identifies which worker types are complements or substitutes in production:

[8] For ease of exposition, we only discuss the case with constant bargaining power. Cahuc/Marque/Wasmer (2008) also derive solutions with heterogeneous bargaining weights for each worker type i.

$$\frac{\partial w_i(\mathsf{N})}{\partial N_j} = \int_0^1 z^{\frac{1}{\beta}} F_{ij}(\mathsf{N}z)\, dz. \tag{15}$$

Specifically, negative shocks to the labor supply of worker type j *raise* wages of workers of type i when j and i are *substitutes* in production ($F_{ij} < 0$) and *lower* wages for workers of type i when i and j are *complements* in production ($F_{ij} > 0$). In a setup with homogenous labor, the model thus nests the prediction from the static model and predicts coworker wage increases after a worker exit when the production function has decreasing returns to scale. For a Cobb-Douglas production function with two skill groups and complementarities between worker groups and perfect substitution within group, e.g., high-skilled and low-skilled workers, wage effects of a high-skilled worker exit would be positive for other high-skilled workers and negative for low-skilled workers.

In the model described in this section, the firm will respond to a worker exit by posting vacancies to converge back to its pre-exit steady state employment level. Therefore, any wage effects will also converge back to zero.

While firms in the model are assumed to post vacancies to instantaneously converge back to the steady state with convex hiring costs, we can also think of perturbations of the steady state in which the firm posts finite vacancies so that the speed of convergence will be inversely related to the search friction that the firm faces. Consider a discrete time version of the search and matching model and let $q_j(\theta_j)$ now denote the per-period probability of filling a vacancy for worker type j. Directly following the worker exit, the wage effect of a j-worker exit on i-worker wages will be $-\frac{\partial w_i(\mathsf{N})}{\partial N_j}$ as employment of worker type j has changed by -1; in the next period, the wage effect will be $-\frac{\partial w_i(\mathsf{N})}{\partial N_j}(1 - q_j(\theta_j))$, in expectation, as the vacancy will have been filled with probability $q_j(\theta_j)$. Note that this illustration ignores higher order terms, e.g., of additional workers leaving the firm. Letting ΔN_{jt} denote the discrepancy between employment of worker type j in period t and the state employment level of worker type j, the cumulative long-run effect of a j-worker exit in $t = 0$ on i-worker wages can be characterized as follows:

$$\sum_{t=0}^{\infty} \frac{\partial w_i(\mathsf{N})}{\partial N_j} \Delta N_{jt} = -\sum_{t=0}^{\infty} \frac{\partial w_i(\mathsf{N})}{\partial N_j}(1 - q_j(\theta_j))^t = -\frac{\partial w_i(\mathsf{N})}{\partial N_j} \frac{1}{q_j(\theta_j)}. \tag{16}$$

According to (16), the magnitude of the cumulative long-run effect of a worker exit on wages is proportional to the search friction that the firm faces when hiring workers of type j. Lower probabilities $q_j(\theta_j)$ of filling a vacancy lead to larger and longer lasting wage effects.

This result demonstrates that the prediction from the static model with replacement workers in section A-2.2 is robust: if firms in thicker labor markets indeed face lower search frictions, the magnitude of wage effects of worker exits will fall with thickness. In addition, this model predicts that longer-run wage effects will be larger in magnitude in tighter labor markets, that is, in labor markets with a high ratio θ_j of vacancies to unemployed workers.

A-3 Evidence on Hours Response (Accident Insurance Data: 2010 to 2015)

We draw on data based on unique information from the German Statutory Accident Insurance to assess the effect of worker deaths on coworkers' work hours. For the years 2010 to 2015, information on workers' hours as reported by the firms are included in the IEB database (see also Gudgeon/Trenkle, forthcoming; Dustmann et al., 2022). Here, we first assess the reliability of the hours data. We then apply our research design for wages using hours-per-week as outcome variable and find no average hours response for the period from 2010 to 2015. However, we find some evidence consistent with negative hours effects of manager and high-skilled worker deaths on workers in other occupations. Overall, we conclude that we find that the hours data from 2010 to 2015 do not point to positive effects. As an important caveat to our analysis, we note that short-run changes in hours, e.g., due to overtime, may be imperfectly captured by the data we analyze.

Reliability of hours data.

Before analyzing potential effects on hours, we discuss the reliability of the hours data and implement several validation tests. Employers could report hours in four different ways (see Dustmann et al., 2022: Online Appendix B.1): i) actual work hours, ii) contractual work hours, iii) hours according to a collective bargaining agreement or the annual fixed full-time reference value calculated by the accident insurance, or iv) a guess. Unfortunately, the data do not include the reporting scheme chosen by the employer. Dustmann et al. (2022) implement several adjustment heuristics to arrive at a measure of contractual working hours which lines up well with data from the German Socio-Economic Panel and the Structure of Earnings Survey (see Table B.2 in their Online Appendix). Since our analysis takes out employer-specific averages, we do not adjust hours across employers (e.g., by adding fixed overtime hours). We tabulate hours per week by gender and benchmark it against data from the Structure of Earnings Survey (*Verdienststrukturerhebung*) 2014 (see Statistisches Bundesamt, 2016). As Appendix Table A-4.15 documents, the summary statistics for the work hours in the administrative data line up very closely with the information from the Structure of Earnings Survey. The average hours per week in the administrative data are 28.6 while the survey average is at 30.91 (including overtime). Both the administrative and the survey data show a pattern of higher work hours per week for men (31.69 vs. 34.66) compared to women (25.25 vs. 26.95). We also plot the distribution of hours per week in Appendix Figure A-4.3. We next follow a validation test from Lachowska/Mas/Woodbury (2022) who assess the reliability of administrative hours measures using data from Washington state. Building on their procedure, we test whether changes log hours from year to year predict changes in log earnings. We find that changes in log hours within individual over time are positively correlated with changes in log earnings ($p < 0.001$), providing support for the reliability of the earnings measures. In addition, we run several other tests of worker-level predictors of work hours and, e.g., find that part-time workers work 11.16 (SE 0.003) fewer hours per week. We also note that Gudgeon/Trenkle (forthcoming), based on the same administrative data sources, report evidence documenting hours responses to a tax notch. For Dustmann et al. (2022), the reform they study occurs after the hours sample ends, although follow-up work has found only limited hours responses to the minimum wage in Germany (see, e.g., Biewen/Fitzenberger/Rümmele, 2022).

While the analyses probing the informativeness of the hours data for our purposes are encouraging (and we do not have evidence to the contrary), we lack a direct, individual benchmarking with validated measures of actual work hours. We thus provide the caveat that the data underlying the following analysis may only imperfectly capture short-run hours changes.

Hours responses.

Figure A-4.4 and columns 1 and 2 in the upper panel of Table A-4.16 extend our main specification to the new sample, using hours per week as outcome variable. We also report summary statistics for the new sample in Tables A-4.17 and A-4.18. On average, we find no evidence for hours increases in response to coworkers deaths. The short- and long-run effects on incumbent work hours are 0.13 (SE 0.17) and 0.06 (SE 0.09), respectively. That is, point estimates are close to zero and not statistically significant. We next assess the effect within and across coworkers in the same occupation (columns 3 and 4 in the upper panel of Table A-4.16) and find effects close to zero for coworkers in the same occupation. In contrast, we find slightly positive effects on workers in other occupations in the short run, with an estimate of 0.29 (SE 0.20). In the long run, the effect is close to zero at 0.07 (SE 0.10). We also analyze effects on wages in the second panel of Table A-4.16. While we detect no average effect, the estimates have wide standard errors that would include our main sample point estimates. A somewhat clearer picture emerges when separately analyzing wage effects in the same occupation as the deceased and in other occupations. For this specification, we detect large, positive effects in the own occupation and large negative effects among workers in other occupations. In the long run, both estimates are statistically significant at 392 (SE 126) in the same occupation and marginally significant at - Euro 264 (SE €138) in other occupations. We have also included analyses of effect heterogeneity by skill group in Table A-4.19. However, for that sample we find very imprecisely estimated wage effects.

The analysis of hours thus reveals that the positive main effect of worker deaths on coworker earnings in the same occupation and the negative ones on workers in other occupations cannot be accounted for through an hours response (although we can only reject the null hypothesis in the long run and have more imprecise estimates in the short run). One potential factor explaining the absence of a positive hours response could be the institutional setup in Germany where labor law, agreements and contracts put sharp upper limits on work hours.[9]

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[9] The Hours of Work Act (ArbZG) puts an eight-hour-per-working-day limit on hours; temporary exceptions to ten hours are permissible if the average work shift balances to eight hours within six months through compensatory time off. In addition, collective bargaining agreements lead to further regulation of working hours.

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A-4 Additional Tables and Figures

Tables

Table A-4.1: Robustness Test: Probability of Future Deaths by Treatment Status

Outcome: Indicator for Worker Death	
Treatment	0.000106
	(0.00023)
Constant	0.011875
	(0.00017)
No. of Observations	1,092,710
No. of Clusters	60,638

Note: The table reports the results of a regression of an indicator variable that is equal to 1 if a firm experienced a worker death in a given year on treatment status for the sample of years after the actual or placebo death. The magnitude of the point estimates implies that firms in the comparison group face a 1.2% probability of a worker death in a given year and that this probability is on average only 0.0106% higher in the treatment group. Standard errors are clustered at the firm level.
Source: Own calculations.

Table A-4.2: Dynamics of Average Treatment Effect on Incumbent Worker Wages

Outcome:	Incumbent Worker Wages	Sum of Incumbent Worker Wages
Treated $\times$ $k = -3$	-20.84	-230.30
	(34.80)	(423.99)
Treated $\times$ $k = -2$	27.89	-31.12
	(28.79)	(327.72)
Treated $\times$ $k = -1$	omitted	omitted
Treated $\times$ $k = 0$	61.61	411.06
	(26.76)	(350.47)
Treated $\times$ $k = 1$	173.40	1582.93
	(37.47)	(430.78)
Treated $\times$ $k = 2$	149.50	1268.66
	(43.40)	(510.19)
Treated $\times$ $k = 3$	126.76	639.15
	(48.49)	(585.57)
Treated $\times$ $k = 4$	82.00	363.90
	(52.59)	(651.35)
Treated $\times$ $k = 5$	-4.41	-566.37
	(56.62)	(722.04)
No. of Observations	6,807,673	6,807,673
No. of Clusters	67,572	67,572

Note: The table reports results based on the dynamic difference-in-differences model in (2). k denotes the year relative to the death of the worker. The mean of incumbent worker wages in year $k = -1$ in the control group is €27,840 (2010 CPI). Observations are weighted inversely by the number of incumbent workers at the firm. Standard errors clustered at the firm level.
Source: Own calculations.

Table A-4.3: Treatment Effects for Additional Samples: Part-Time Incumbents and Apprentices

Sample:	Part-Time Incumbents		Apprentices		Main Sample: Full-Time Incumbents	
	Short-Run Effect	Long-Run Effect	Short-Run Effect	Long-Run Effect	Short-Run Effect	Long-Run Effect
Outcome: Wages						
Treated	159.66	150.70	117.66	109.62	153.78	103.30
	(83.47)	(85.21)	(82.73)	(85.14)	(36.37)	(38.42)
Outcome: Employed at Same Establishment						
Treated	0.0010	0.0021	0.0126	0.0149	0.0032	0.0036
	(0.0038)	(0.0038)	(0.0050)	(0.0038)	(0.0013)	(0.0014)
Outcome: Full-Time Employment						
Treated	0.0019	0.0036	0.0016	-0.0006	0.0007	-0.0015
	(0.0027)	(0.0027)	(0.0052)	(0.0034)	(0.0010)	(0.0010)
Outcome: Part-Time Employment						
Treated	-0.0044	-0.0024	-0.0002	0.0009	0.0000	0.0005
	(0.0039)	(0.0037)	(0.0013)	(0.0012)	(0.0004)	(0.0005)
Outcome: Promotion						
Treated	0.0013	0.0003	-0.0006	-0.0001	0.0009	0.0014
	(0.0011)	(0.0011)	(0.0012)	(0.0010)	(0.0003)	(0.0003)
No. of Observations	649049	649049	351895	351895	6807673	6807673
Outcome: Occupation Mean Wage						
Treated	-0.0029	-0.0026	0.0015	0.0018	0.0012	0.0009
	(0.0032)	(0.0031)	(0.0030)	(0.0026)	(0.0015)	(0.0014)
No. of Observations	517426	517426	249934	249934	5686709	5686709

Note: The table displays treatment effects on several employment outcomes based on difference-in-differences regressions. The sample of part-time incumbents is defined as the set of part-time coworkers of the deceased in the year before death. Apprentices are defined as apprentices at the incumbent's firm in the year before death. The full-time incumbent sample is the main sample used for the analysis in the paper and included here as a benchmark. Treated refers to the Post $\times$ Treated coefficient. Short-run effects refer to the diff-in-diff effects using year $k = 1$ post-death as the post period; long-run effects refer to the specifications using years 1 through 5 post-death as the post period. Employed at the same establishment is an outcome variable that is equal to one when an incumbent worker is still employed at the same establishment as in year $k = -1$. Full- and part-time employment are outcome variables that indicate the respective employment status independent of the establishment at which the individual is employed. Promotion is an outcome variable that is equal to 1 when an individual is employed at the same establishment in an occupation with an higher average wage than the occupation he or she worked in in year $k = -1$. To calculate average wages at the 5 digit occupation level, we draw a 10% sample of individuals from the IEB and regress individual's log wage on occupation dummies and individual fixed effects. We use the estimated occupation effects to measure promotions. Observations are weighted inversely by the number of incumbent workers at the firm of the deceased.
Source: Own calculations.

Table A-4.4: Dynamics of Average Treatment Effect on New Hire Wages

Outcome:	New Hire Wages
Treated $\times$ $k = -3$	112.21
	(79.80)
Treated $\times$ $k = -2$	174.54
	(79.94)
Treated $\times$ $k = -1$	omitted
Treated $\times$ $k = 0$	169.55
	(77.66)
Treated $\times$ $k = 1$	1201.31
	(79.38)
Treated $\times$ $k = 2$	727.01
	(84.48)
Treated $\times$ $k = 3$	283.66
	(87.68)
Treated $\times$ $k = 4$	74.49
	(90.65)
Treated $\times$ $k = 5$	159.68
	(93.55)
No. of Observations	4,130,064
No. of Clusters	67,044

Note: The table reports results based on the dynamic difference-in-differences model in (2), with new hire wages as the outcome variable. k denotes the year relative to the death of the worker. The mean of new hire worker wages in year $k = -1$ in the control group is €17106.04 (2010 CPI)

Source: Own calculations. .

Table A-4.5: New Hire Characteristics

	Wages	Age	New Hire Education			New Hire Experience		
			Low	Medium	High	Industry	Occupation	Overall
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Short-run	1201.31	0.70	0.0008	0.0008	-0.0015	0.12	0.20	0.12
	(79.38)	(0.09)	(0.0031)	(0.0036)	(0.0021)	(0.02)	(0.03)	(0.02)
Long-run	557.63	0.33	-0.0010	0.0036	0.0007	0.05	0.08	0.05
	(61.47)	(0.06)	(0.0029)	(0.0034)	(0.0020)	(0.02)	(0.02)	(0.02)
No. of Observations	4130064	4130064		4130064		4087981	4088049	4088049

Note: The table reports treatment effects on incumbent worker wages based on difference-in-differences (DiD) regressions. Short-run effects refer to the DiD effects using year $k = 1$ post-death as the post period; long-run effects refer to the specifications using years 1 through 5 post-death as the post period. Standard errors are clustered at the firm level.
Source: Own calculations.

Table A-4.6: Wage Effects and External Labor Market Characteristics

Outcome: Wages of Incumbent Workers Co-Worker Sample:	All Worker Deaths		Worker Deaths in High Specialization Occupations		Worker Deaths in Low Specialization Occupations	
	Short-Run Effect (1)	Long-Run Effect (2)	Short-Run Effect (3)	Long-Run Effect (4)	Short-Run Effect (5)	Long-Run Effect (6)
(A) Thickness Measured at Occupation Level						
Treated × Low Thickness (Occupation)	207.50	100.70	323.20	190.24	116.04	31.33
	(53.78)	(59.24)	(78.04)	(85.18)	(73.94)	(81.92)
Treated × High Thickness (Occupation)	139.25	110.19	71.71	5.88	188.37	184.95
	(52.19)	(57.89)	(76.90)	(85.99)	(70.77)	(77.94)
(B) Density of Local Labor Market						
Treated × Low Density	211.15	128.33	211.70	107.83	210.55	143.67
	(51.81)	(57.27)	(75.12)	(82.76)	(71.23)	(78.87)
Treated × High Density	135.52	82.27	188.28	92.19	96.18	75.62
	(54.16)	(59.82)	(79.95)	(88.47)	(73.39)	(80.83)
(C) Thickness Measured at Industry Level						
Treated × Low Thickness (Industry)	210.67	167.16	279.78	157.27	154.79	176.22
	(53.61)	(58.85)	(77.24)	(85.32)	(74.17)	(81.01)
Treated × High Thickness (Industry)	140.70	53.73	118.03	46.11	156.50	57.25
	(52.24)	(57.72)	(77.45)	(84.53)	(70.45)	(78.29)
(D) Local Unemployment Rate						
Treated × Low Unemployment	131.33	74.70	157.80	118.42	110.16	38.67
	(59.61)	(66.39)	(86.46)	(96.13)	(81.97)	(91.31)
Treated × High Unemployment	201.47	107.07	227.10	73.73	181.64	130.88
	(57.46)	(64.18)	(83.65)	(93.34)	(78.65)	(87.83)
N	6807673		2765682		4041991	

Note: The table shows heterogeneity of the treatment effect based on the difference-in-differences framework in equation (2). Short-run effects refer to the treatment effects in year $k = 1$ post-death; long-run effects refer to the average treatment effects in years $k = 1$ through $k = 5$. Covariates that are included as interactions with treatment status are also included as baseline effects, i.e., as an interaction of the baseline period effect 1(period$_k$) with the covariate. To calculate a specialization measure for the occupation of the deceased worker, we follow Bleakley/Lin (2012) and calculate returns to experience for each 5-digit occupation. We then use the estimated occupation-specific returns to experience to classify occupations into high- and low-specialization occupations based on a median split. All external labor market characteristics are measured at the commuting zone level based on median splits of the relevant measure. Thickness measured at the occupation level is used to categorize 5-digit occupation × commuting zone cells as thick or thin based on the relative share of workers in the 5-digit occupation in the commuting zone relative to the overall share of workers in that occupation in the labor market. Thickness measured at the industry level is defined analogously for the share of workers in the 3-digit industry × commuting zone level. Density of the local labor market refers to the number of workers in a commuting zone divided by that commuting zone's area. The unemployment rate is calculated as the number of unemployed workers in the commuting zone divided by the number of workers. Observations are weighted inversely by the number of incumbent workers at the firm of the deceased. Standard errors are clustered at the firm level.
Source: Own calculations.

Table A-4.7: Heterogeneity of Hiring Responses and External Labor Market Characteristics

Outcome: Hiring of Workers Sample:	All Worker Deaths		Worker Deaths in High Specialization Occupations		Worker Deaths in Low Specialization Occupations	
	Short-Run Effect (1)	Long-Run Effect (2)	Short-Run Effect (3)	Long-Run Effect (4)	Short-Run Effect (5)	Long-Run Effect (6)
(A) Thickness Measured at Occupation Level						
Treated × Low Thickness (Occupation)	0.38	0.17	0.36	0.18	0.40	0.16
	(0.05)	(0.04)	(0.06)	(0.05)	(0.07)	(0.05)
Treated × High Thickness (Occupation)	0.42	0.15	0.48	0.17	0.38	0.14
	(0.03)	(0.03)	(0.05)	(0.05)	(0.04)	(0.04)
(B) Density of Local Labor Market						
Treated × Low Density	0.42	0.15	0.41	0.15	0.43	0.15
	(0.03)	(0.03)	(0.05)	(0.05)	(0.04)	(0.04)
Treated × High Density	0.38	0.16	0.43	0.19	0.34	0.14
	(0.05)	(0.04)	(0.06)	(0.05)	(0.07)	(0.05)
(C) Thickness Measured at Industry Level						
Treated × Low Thickness (Industry)	0.37	0.16	0.35	0.17	0.38	0.16
	(0.04)	(0.04)	(0.06)	(0.06)	(0.06)	(0.05)
Treated × High Thickness (Industry)	0.43	0.15	0.50	0.18	0.39	0.14
	(0.04)	(0.03)	(0.05)	(0.04)	(0.05)	(0.04)
(D) Local Unemployment Rate						
Treated × Low Unemployment	0.45	0.20	0.45	0.24	0.45	0.17
	(0.04)	(0.04)	(0.05)	(0.05)	(0.07)	(0.05)
Treated × High Unemployment	0.38	0.15	0.40	0.15	0.36	0.15
	(0.04)	(0.04)	(0.07)	(0.06)	(0.06)	(0.04)
Number of firms	67,572		29,341		38,231	
Number of observations	608148		264069		344079	

Note: The table shows heterogeneity of the treatment effect based on the difference-in-differences framework in equation (2). Short-run effects refer to the treatment effects in year $k = 1$ post-death; long-run effects refer to the average treatment effects in years $k = 1$ through $k = 5$. Covariates that are included as interactions with treatment status are also included as baseline effects, i.e., as an interaction of the baseline period effect 1(period$_k$) with the covariate. To calculate a specialization measure for the occupation of the deceased worker, we follow Bleakley/Lin (2012) and calculate returns to experience for each 5-digit occupation. We then use the estimated occupation-specific returns to experience to classify occupations into high- and low-specialization occupations based on a median split. All external labor market characteristics are measured at the commuting zone level based on median splits of the relevant measure. Thickness measured at the occupation level is used to categorize 5-digit occupation × commuting zone cells as thick or thin based on the relative share of workers in the 5-digit occupation in the commuting zone relative to the overall share of workers in that occupation in the labor market. Thickness measured at the industry level is defined analogously for the share of workers in the 3-digit industry × commuting zone level. Density of the local labor market refers to the number of workers in a commuting zone divided by that commuting zone's area. The unemployment rate is calculated as the number of unemployed workers in the commuting zone divided by the number of workers. Observations are weighted inversely by the number of incumbent workers at the firm of the deceased. Standard errors are clustered at the firm level.
Source: Own calculations.

Table A-4.8: Heterogeneity of Hiring of Workers in Same Occupation As Decease and External Labor Market Characteristics

Outcome: Hiring of Workers in the Same Occupation Group as the Deceased						
Sample:	All Worker Deaths		Worker Deaths in High Specialization Occupations		Worker Deaths in Low Specialization Occupations	
	Short-Run Effect (1)	Long-Run Effect (2)	Short-Run Effect (3)	Long-Run Effect (4)	Short-Run Effect (5)	Long-Run Effect (6)
(A) Thickness Measured at Occupation Level						
Treated × Low Thickness (Occupation)	0.34	0.13	0.32	0.11	0.36	0.14
	(0.03)	(0.02)	(0.05)	(0.04)	(0.03)	(0.03)
Treated × High Thickness (Occupation)	0.35	0.14	0.36	0.15	0.34	0.13
	(0.02)	(0.02)	(0.04)	(0.04)	(0.03)	(0.03)
(B) Density of Local Labor Market						
Treated × Low Density	0.35	0.13	0.35	0.13	0.36	0.13
	(0.03)	(0.02)	(0.04)	(0.04)	(0.03)	(0.03)
Treated × High Density	0.34	0.14	0.33	0.13	0.34	0.14
	(0.03)	(0.02)	(0.05)	(0.04)	(0.04)	(0.03)
(C) Thickness Measured at Industry Level						
Treated × Low Thickness (Industry)	0.32	0.15	0.30	0.14	0.33	0.15
	(0.03)	(0.03)	(0.05)	(0.05)	(0.04)	(0.03)
Treated × High Thickness (Industry)	0.37	0.12	0.39	0.12	0.36	0.12
	(0.02)	(0.02)	(0.04)	(0.03)	(0.03)	(0.03)
(D) Local Unemployment Rate						
Treated × Low Unemployment	0.38	0.15	0.35	0.15	0.40	0.16
	(0.03)	(0.03)	(0.04)	(0.04)	(0.04)	(0.03)
Treated × High Unemployment	0.32	0.13	0.33	0.13	0.31	0.13
	(0.03)	(0.03)	(0.06)	(0.04)	(0.03)	(0.03)
Number of firms	67,572		29,341		38,231	
Number of observations	608148		264069		344079	

Note: The table shows heterogeneity of the treatment effect based on the difference-in-differences framework in equation (2). Short-run effects refer to the treatment effects in year $k = 1$ post-death; long-run effects refer to the average treatment effects in years $k = 1$ through $k = 5$. Covariates that are included as interactions with treatment status are also included as baseline effects, i.e., as an interaction of the baseline period effect 1(period$_k$) with the covariate. Hires are counted if they are in the same 1-digit occupation group as the deceased. To calculate a specialization measure for the occupation of the deceased worker, we follow Bleakley/Lin (2012) and calculate returns to experience for each 5-digit occupation. We then use the estimated occupation-specific returns to experience to classify occupations into high- and low-specialization occupations based on a median split. All external labor market characteristics are measured at the commuting zone level based on median splits of the relevant measure. Thickness measured at the occupation level is used to categorize 5-digit occupation × commuting zone cells as thick or thin based on the relative share of workers in the 5-digit occupation in the commuting zone relative to the overall share of workers in that occupation in the labor market. Thickness measured at the industry level is defined analogously for the share of workers in the 3-digit industry × commuting zone level. Density of the local labor market refers to the number of workers in a commuting zone divided by that commuting zone's area. The unemployment rate is calculated as the number of unemployed workers in the commuting zone divided by the number of workers. Observations are weighted inversely by the number of incumbent workers at the firm of the deceased. Standard errors are clustered at the firm level.
Source: Own calculations.

Table A-4.9: Effects on Incumbent Worker Wages in Year $k = 0$ By Quarter of Death

Outcome:	Wage in Year $k = 0$
Treated $\times$ Death in July, August, September of $k = 0$	162.75
	(41.30)
Treated $\times$ Death in October, November, December of $k = 0$	56.37
	(42.62)
Treated $\times$ Death in January, February, March of $k = 1$	18.04
	(43.18)
Treated $\times$ Death in April, May, June of $k = 1$	-1.62
	(42.37)
No. of Observations	765,743
No. of Clusters	67,572

Note: The table displays results of a difference-in-differences regression of wages in year $k = 0$ on treatment status interacted with dummies for the quarter of death of the deceased worker in the treated group. The positive and statistically significant coefficients for wage effects in year 0 of deaths that occur in Q3 or Q4 of $k = 0$ document that the positive wage effects in year $k = 0$ (see, e.g., Figure (2)) are driven by deaths that occur in the same calendar year, as wages for most employees correspond to average wages calculated over a calendar year horizon so that deaths in, e.g., August will have an effect on average wages in that year. The table also demonstrates that deaths in the first quarter of the following calendar year do not have a statistically detectable effect on incumbent worker wages in the previous calendar year. Standard errors are based on 67,572 clusters at the worker death level. Observations are weighted inversely by the number of incumbent workers at the firm of the deceased.
Source: Own calculations.

Table A-4.10: Wages Effects in Firms with High vs. Low Wage Flexibility

	Incumbent Worker Wages	
	Short-run	Long-run
	(1)	(2)
Treated x Low Flex	166.325	147.06
	(55.36)	(61.70)
Treated x High Flex	167.69	66.70
	(50.02)	(54.94)
Treated x Low Flex x Same Occ	218.82	145.86
	(69.85)	(76.73)
Treated x Low Flex x Other Occ	72.63	148.93
	(84.86)	(95.21)
Treated x High Flex x Same Occ	243.92	186.85
	(62.58)	(68.81)
Treated x High Flex x Other Occ	43.19	-131.19
	(76.66)	(82.66)
No. of Observations	6,807,673	6,807,673

Note: The table displays treatment effects on incumbent worker wages based on difference-in-differences (DiD) regressions. Treated refers to the Post $\times$ Treated coefficient. Short-run effects refer to the DiD effects using year $k = 1$ post-death as the post period; long-run effects refer to the specifications using years 1 through 5 post-death as the post period. We calculate wage rigidity or flexibility measures following Jäger et al. (2020). "High" wage flexibility is defined as an above median standard deviation of pre-period wage changes, implying less rigid wage setting policies of the firm. Same Occupation and Other Occupation are dummy variables, indicating whether an incumbent worker was in the same 1-digit occupation group as the deceased or in a different occupation in the year before a worker death. Standard errors are clustered at the firm level.
Source: Own calculations.

Table A-4.11: Wage Effect Heterogeneity by Relative Ranking of Deceased

Dimension of Heterogeneity	Relative Wage Rank Deceased		Top 25% Rank Deceased		Promotion	
	Short Run	Long Run	Short Run	Long Run	Short Run	Long Run
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A:						
Treated × Lower	134.85	254.21	175.54	113.62	0.0007	0.0011
	(67.20)	(74.11)	(44.16)	(48.69)	(0.0005)	(0.0005)
Treated × Same					0.0001	0.0007
					(0.0004)	(0.0004)
Treated × Higher	211.59	115.38	168.83	83.23	0.0025	0.0025
	(52.51)	(54.95)	(69.19)	(77.04)	(0.0008)	(0.0008)
Panel B:						
Treated × Lower × Same Occupation	268.53	187.99	277.56	145.50		
	(77.97)	(71.90)	(106.22)	(63.95)		
Treated × Lower × Other Occupation	-71.36	92.88	143.46	57.38		
	(106.94)	(79.58)	(119.07)	(82.61)		
Treated × Higher × Same Occupation	296.73	346.09	198.90	160.95		
	(68.89)	(85.35)	(92.10)	(117.37)		
Treated × Higher × Other Occupation	212.58	-29.78	52.84	90.46		
	(74.86)	(118.80)	(102.83)	(128.83)		
No. of Observations	6,807,673	6,807,673	6,807,673	6,807,673	6,807,673	6,807,673
No. of Clusters	67,572	67,572	67,572	67,572	67,572	67,572

Note: The table shows heterogeneity of the treatment effect based on the difference-in-differences framework in equation (2). Short-run effects refer to the treatment effects in year $k = 1$ post-death; long-run effects refer to the average treatment effects in years $k = 1$ through $k = 5$. Covariates that are included as interactions with treatment status are also included as baseline effects, i.e., as an interaction of the baseline period effect $1(\text{period}_k)$ with the covariate. In Column (1) and (2) *Lower* and *Higher* refer to the wage ranking of the deceased relative to a given incumbent worker. For Column (3) and (4) *Lower* and *Higher* indicate whether the deceased worker was ranked lower or within the top 25% of the firm in terms of salary. In Column (5) and (6) *Lower*, *Same* and *Higher* refer to the ranking of the deceased relative to the incumbent worker in terms of the average pay in their respective occupations. Same Occupation and Other Occupation are dummy variables, indicating whether an incumbent worker was in the same 1-digit occupation group as the deceased or in a different occupation in the year before a worker death. Observations are weighted inversely by the number of incumbent workers at the firm of the deceased. Standard errors are clustered at the firm level.
Source: Own calculations.

Table A-4.12: Effects of Weekend Deaths

	Incumbent Worker Wages	
	Short-Run	Long-Run
	(1)	(2)
Treated x Weekend	284.16	270.88
	(71.15)	(78.62)
No. of Observations	1,911,469	1,911,469
Main Results:		
Treated	173.40	105.45
	(37.47)	(41.42)
No. of Observations	6,807,673	6,807,673

Note: The table reports treatment effects on incumbent worker wages based on difference-in-differences (DiD) regressions. Treated refers to the Post $\times$ Treated coefficient. Short-run effects refer to the DiD effects using year $k = 1$ post-death as the post period; long-run effects refer to the specifications using years 1 through 5 post-death as the post period. Standard errors are clustered at the firm level.
Source: Own calculations.

Table A-4.13: Effects of Worker Death on Hiring and Retention

Dimension of Heterogeneity:	Education		Skill		Managerial Status		Tenure		Specialization	
	Short Run	Long Run	Short Run	Long Run	Short Run	Long Run	Short Run	Long Run	Short Run	Long Run
Hiring (all)										
Treated × Low	0.33	0.05	0.36	0.13	0.42	0.16	0.26	0.12	0.37	0.11
	(0.08)	(0.06)	(0.07)	(0.06)	(0.03)	(0.03)	(0.11)	(0.09)	(0.06)	(0.05)
Treated × Medium	0.42	0.18	0.44	0.17			0.36	0.12	0.39	0.16
	(0.03)	(0.03)	(0.03)	(0.03)			(0.05)	(0.04)	(0.04)	(0.03)
Treated × High	0.37	0.16	0.33	0.15	0.27	0.15	0.47	0.22	0.48	0.22
	(0.10)	(0.11)	(0.07)	(0.06)	(0.10)	(0.06)	(0.03)	(0.03)	(0.07)	(0.07)
Hiring (same occupation)										
Treated × Low	0.26	0.04	0.29	0.12	0.32	0.11	0.31	0.13	0.22	0.04
	(0.06)	(0.05)	(0.05)	(0.05)	(0.02)	(0.02)	(0.05)	(0.04)	(0.03)	(0.03)
Treated × Medium	0.31	0.12	0.33	0.12			0.28	0.11	0.31	0.11
	(0.02)	(0.02)	(0.02)	(0.02)			(0.03)	(0.03)	(0.02)	(0.02)
Treated × High	0.22	0.06	0.18	0.06	0.15	0.07	0.31	0.11	0.36	0.16
	(0.05)	(0.06)	(0.03)	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.04)	(0.05)
Employment										
Treated × Low	-0.39	-0.28	-0.37	-0.13	-0.31	-0.11	-0.39	-0.04	-0.35	-0.08
	(0.09)	(0.13)	(0.09)	(0.12)	(0.04)	(0.05)	(0.12)	(0.17)	(0.08)	(0.11)
Treated × Medium	-0.33	-0.10	-0.29	-0.11			-0.38	-0.18	-0.36	-0.17
	(0.04)	(0.05)	(0.04)	(0.06)			(0.06)	(0.08)	(0.05)	(0.06)
Treated × High	-0.31	0.04	-0.48	-0.15	-0.53	-0.20	-0.36	-0.11	-0.27	0.00
	(0.13)	(0.23)	(0.09)	(0.12)	(0.11)	(0.15)	(0.04)	(0.06)	(0.08)	(0.13)
Retention										
Treated × Low	0.0040	-0.0012	0.0059	0.0016	0.0037	0.0013	0.0047	0.0026	0.0030	0.0016
	(0.0034)	(0.0017)	(0.0028)	(0.0014)	(0.0014)	(0.0007)	(0.0036)	(0.0019)	(0.0027)	(0.0013)
Treated × Medium	0.0030	0.0013	0.0038	0.0008			0.0032	0.0006	0.0042	0.0011
	(0.0014)	(0.0007)	(0.0016)	(0.0008)			(0.0021)	(0.0011)	(0.0016)	(0.0008)
Treated × High	0.0020	0.0028	-0.0025	0.0013	-0.0011	-0.0004	0.0012	0.0013	-0.0012	0.0001
	(0.0054)	(0.0027)	(0.0031)	(0.0016)	(0.0037)	(0.0018)	(0.0019)	(0.0009)	(0.0034)	(0.0017)
No. of Observations	608148		608148		608148		608148		608148	

Note: The table shows results based on the difference-in-differences framework in equation (2). The outcome variable are all new hires and new hires within the same 5-digit occupation as the deceased. Short-run effects refer to the treatment effects in year $k = 1$ post-death; long-run effects refer to the average treatment effects in years $k = 1$ through $k = 5$. Covariates that are included as interactions with treatment status are also included as baseline effects, i.e., as an interaction of the baseline period effect 1(period$_k$) with the covariate. Low, medium, and high education indicate the education level of the deceased worker: low education - less than apprenticeship training, medium education - apprenticeship training, and high education - formal education beyond apprenticeship training. Low-, medium-, and high-skilled occupations are indicators for the skill intensity of the deceased's 5-digit occupation as measured by the average years of education of workers in the occupation. Low-, medium-, and high-skilled occupations are defined as occupations below the 20th percentile, between the 20th and 80th percentile, and above the 80th percentile of average years of education, respectively. Low, medium, and high tenure are categorized as 1 to 5 years (low), 5 to 10 years (medium), and greater than 10 years of tenure (high). To calculate a specialization measure for the occupation of the deceased worker, we follow Bleakley/Lin (2012) and calculate returns to experience for each 5-digit occupation. We then use the estimated occupation-specific returns to experience to classify occupations as follows: occupations with returns to experience below the 20th percentile are classified as low specialization occupations, occupations with returns to experience between the 20th and 80th percentile are classified as medium specialization, and occupations above the 80th percentile of returns to experience as high specialization occupations. In the manager column, low refers to workers we identify as non-managers and high refers to managers. We measure the managerial status of the deceased's occupation as proxied by occupations requiring "complex specialist activities" (requirement level 3) or "highly complex activities" (requirement level 4) based on the 2010 Classification of Occupations. These occupations are characterized by managerial, planning and control activities, such as operation and work scheduling, supply management, and quality control and assurance and typically require a qualification as master craftsperson, graduation from a professional academy, or university studies (see *Klassifikation der Berufe 2010, Band 1: Systematischer und alphabetischer Teil mit Erläuterungen, Bundesagentur für Arbeit*). Observations are weighted inversely by the number of incumbent workers at the firm of the deceased. Robust standard errors in parentheses.
Source: Own calculations.

Table A-4.14: Estimation of Model Parameters and Implied Replacement Costs
Extensions to the Baseline Model

A. Extension with intensive margin:		
	Baseline Estimation	Intensive Margin
γ	76054	53145
λ	0.09	0.04
η	0.20	0.49
$\overline{w}$	45448	33383
ϵ	1.33	4.96
P^0	1147740	69973
Marginal Replacement Cost ($c'(\frac{N}{I})$)	65449	37727
(Expressed as % of incumbent salary)	(232%)	(134%)
B. Extension to two worker types (by occupation):		
	Occupation Calibration	
$\gamma_{\text{same occ}}$	68826	
$\lambda_{\text{same occ}}$	0.08	
$\eta_{\text{same occ}}$	0.21	
$\overline{w}_{\text{same occ}}$	43544	
$\gamma_{\text{other occ}}$	117651	
$\lambda_{\text{other occ}}$	0.21	
$\eta_{\text{other occ}}$	0.16	
$\overline{w}_{\text{other occ}}$	47634	
$A_{\text{other occ}}$	1.17	
ρ	0.85	
ϵ	[1.5]	
P^0	1831712	
Marginal Replacement Cost ($c'(\frac{N}{I})$)	59504	
(Expressed as % of incumbent salary)	(211%)	

Note: The table replicates the specification in Table (7) in column 1. The intensive-margin column reports estimation results when allowing for an hours response (see Section A-1.4). The occupation calibration draws on the two-type model and reports results additional results for the substitutability of workers across occupational boundaries.
Source: Own calculations.

Table A-4.15: Summary Statistics on Hours per Week in Administrative Data and Structure of Earnings Survey

	All Workers		
	Administrative Data	Survey (Excluding Overtime)	Survey (Overtime)
Mean	28.60	30.62	0.29
Standard Deviation	11.39	12.53	1.49
	Women		
	Administrative Data	Survey (Excluding Overtime)	Survey (Overtime)
Mean	25.25	26.81	0.14
Standard Deviation	10.93	12.77	0.99
	Men		
	Administrative Data	Survey (Excluding Overtime)	Survey (Overtime)
Mean	31.69	34.24	0.42
Standard Deviation	11.05	11.15	1.83

Note: The table reports hours per week based on administrative data from the German Statutory Accident Insurance as well as data from the Structure of Earnings Survey 2014 (*Verdienststrukturerhebung*, p. 118). The German Statutory Accident Insurance required all firms to report information on workers' hours of work as part of their administrative reporting processes in the time period from 2010 to 2015. We drop outlier observations below the 1st and above the 99th percentile.The administrative data include overtime measures while the survey separately asks for hours (excluding overtime) and overtime hours.
Source: Own calculations.

Table A-4.16: Effects on Hours per Week and Incumbent Worker Wages

Outcome: Incumbent Worker Hours				
	Short-Run Effect	Long-Run Effect	Short-Run Effect	Long-Run Effect
Treated	0.13	0.06		
	(0.17)	(0.09)		
Treated × Same Occupation			-0.06	0.04
			(0.26)	(0.13)
Treated × Other Occupations			0.29	0.07
			(0.20)	(0.10)
Outcome: Incumbent Worker Wages				
Treated	-28.88	33.77		
	(121.28)	(97.14)		
Treated × Same Occupation			200.53	392.17
			(152.01)	(125.52)
Treated × Other Occupations			-217.22	-263.77
			(175.81)	(137.87)
No. of Observations	188,609	188,609	188,609	188,609
No. of Clusters	7,673	7,673	7,673	7,673

Note: The table shows heterogeneity of the treatment based on the difference-in-differences framework in equation (2). The outcome variable are incumbent worker wages and hours per week among incumbent workers. The German Statutory Accident Insurance required all firms to report information on workers' hours of work as part of their administrative reporting processes in the time period from 2010 to 2015. Short-run effects refer to the treatment effects in year $k = 1$ post-death; long-run effects refer to the average treatment effects in years $k = 1$ through $k = 5$. Covariates that are included as interactions with treatment status are also included as baseline effects, i.e., as an interaction of the baseline period effect 1(period$_k$) with the covariate. Same Occupation and Other Occupation are dummy variables indicating whether an incumbent worker was in the same 1-digit occupation group as the deceased or in a different occupation in the year before a worker death. Low-, medium-, and high-skilled occupations are indicators for the skill intensity of the deceased's 5-digit occupation as measured by the average years of education of workers in the occupation. Low-, medium-, and high-skilled occupations are defined as occupations below the 20th percentile, between the 20th and 80th percentile, and above the 80th percentile of average years of education, respectively. Low, medium, and high education indicate the education level of the deceased worker: low education - less than apprenticeship training, medium education - apprenticeship training, and high education - formal education beyond apprenticeship training. We measure the managerial status of the deceased's occupation as proxied by occupations requiring "complex specialist activities" (requirement level 3) or "highly complex activities" (requirement level 4) based on the 2010 Classification of Occupations. These occupations are characterized by managerial, planning and control activities, such as operation and work scheduling, supply management, and quality control and assurance and typically require a qualification as master craftsperson, graduation from a professional academy, or university studies (see *Klassifikation der Berufe 2010, Band 1: Systematischer und alphabetischer Teil mit Erläuterungen, Bundesagentur für Arbeit*). Observations are weighted inversely by the number of incumbent workers at the firm of the deceased. Standard errors are clustered at the firm level.
Source: Own calculations.

Table A-4.17: Individual-Level Summary Statistics (Hours Sample)

	Actual and Placebo Deceased Workers		Incumbent Workers	
	Treatment Group	Comparison Group	Treatment Group	Comparison Group
Age	49.81	49.81	42.75	42.68
	(8.70)	(8.70)	(10.90)	(10.91)
Female	0.16	0.16	0.27	0.27
	(0.36)	(0.36)	(0.44)	(0.44)
Earnings (€, 2010 CPI)	24995.83	24969.66	27473.63	27328.42
	(10945.11)	(10747.30)	(15118.26)	(14830.99)
Years of Education	10.33	10.34	10.53	10.59
	(1.15)	(1.21)	(1.53)	(1.51)
Tenure (Years)	6.29	6.20	4.85	4.84
	(2.26)	(2.31)	(2.24)	(2.25)
N	3,886	3,886	42,202	42,682

Note: The first two columns show summary statistics for the actual and placebo deceased worker in the treatment and comparison group. The second two columns show summary statistics for the sample of incumbent workers, i.e., full-time coworkers of the actual or placebo deceased in the year before the actual or placebo death. Standard deviations are reported in parentheses. All variables are measured in $k = -1$, the year before the actual or placebo death. For the incumbent worker sample, observations are weighted inversely by the number of incumbent workers at a firm. Earnings are real annual earnings in €(2010 CPI). Years of education are calculated as follows: 9 years for individuals with no degree, 10.5 years for individuals with only an apprenticeship training, 13 years for individuals with a general qualification for university entrance (*Abitur*), 14.5 years for individuals with *Abitur* and an apprenticeship training, 16 years for individuals with a degree from a technical college or a university of applied sciences, and 18 years for individuals with a university degree.
Source: Own calculations.

Table A-4.18: Firm-Level Summary Statistics (Hours Sample)

	Treatment Group	Comparison Group
Total Number of Employees	15.59	15.36
	(7.44)	(7.24)
Number Part-Time Workers	2.79	2.58
	(3.20)	(2.93)
Number Apprentices	0.72	0.76
	(1.33)	(1.34)
Firm Age	7.58	7.57
	(1.13)	(1.14)
Primary Sector	0.02	0.02
	(0.16)	(0.14)
Secondary Sector (Manufacturing)	0.43	0.44
	(0.50)	(0.50)
Tertiary Sector (Service)	0.54	0.54
	(0.50)	(0.50)
N	3,921	3,921

Note: Standard deviations are reported in parentheses. All variables are measured in $k = -1$, the year before the actual or placebo death. Firm age refers to the number of years the establishment ID has been observed in the data.
Source: Own calculations.

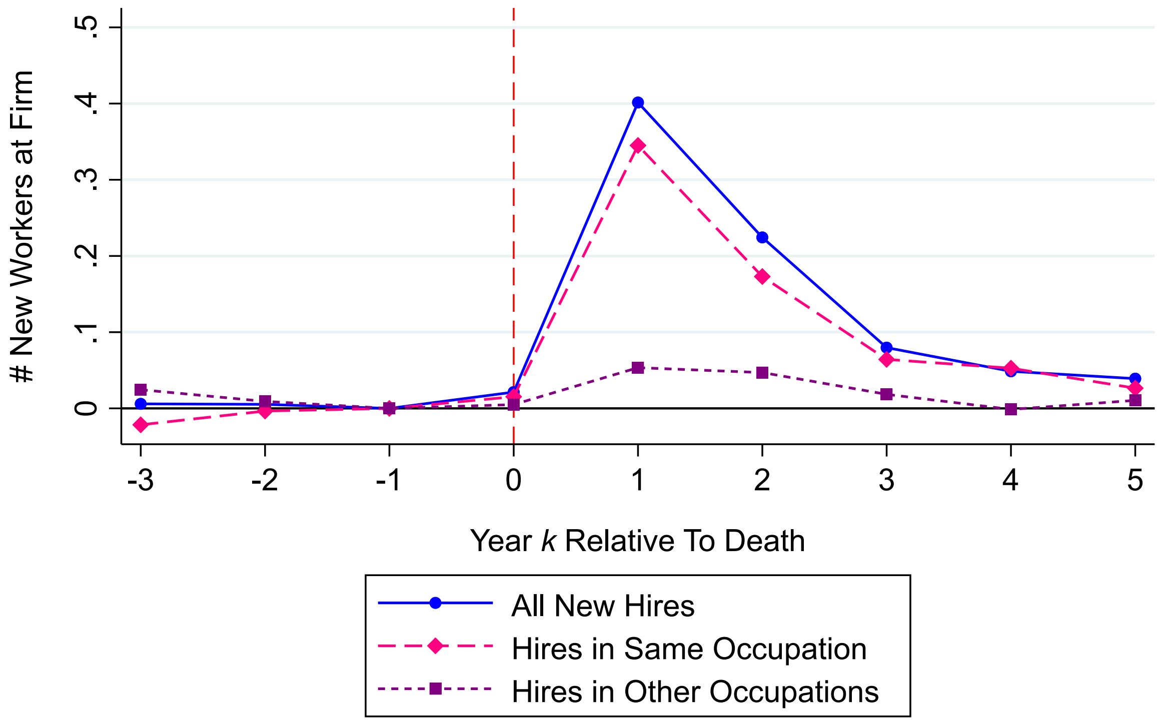
Table A-4.19: Heterogeneity in Effects on Hours per Week

Outcome: Incumbent Worker Hours						
Dimension of Heterogeneity:	Skill		Education		Managerial Status	
	Short-Run Effect	Long-Run Effect	Short-Run Effect	Long-Run Effect	Short-Run Effect	Long-Run Effect
	(1)	(2)	(3)	(4)	(5)	(6)
Treated × Low	0.92	0.06	0.56	0.07	0.20	0.07
	(0.38)	(0.18)	(0.37)	(0.18)	(0.19)	(0.10)
Treated × Medium	-0.01	0.10	0.00	0.06		
	(0.23)	(0.11)	(0.20)	(0.11)		
Treated × High	-0.18	-0.06	-0.29	-0.03	-0.23	-0.04
	(0.29)	(0.16)	(0.52)	(0.26)	(0.37)	(0.18)
Outcome: Incumbent Worker Wages						
Treated × Low	-48.81	-27.76	298.91	240.61	-82.61	-20.29
	(237.60)	(186.89)	(214.29)	(174.76)	(129.08)	(102.20)
Treated × Medium	-29.80	11.62	-170.30	-47.44		
	(159.60)	(125.26)	(152.73)	(120.46)		
Treated × High	-34.50	158.29	-38.31	-40.81	248.81	338.95
	(285.94)	(242.56)	(474.93)	(403.63)	(341.17)	(287.43)
No. of Observations	188,609	188,609	188,609	188,609	188,609	188,609
No. of Clusters	7,673	7,673	7,673	7,673	7,673	7,673

Note: The table shows heterogeneity of the treatment based on the difference-in-differences framework in equation (2). The outcome variable are hours per week among incumbent workers. The German Statutory Accident Insurance required all firms to report information on workers' hours of work as part of their administrative reporting processes in the time period from 2010 to 2015. Short-run effects refer to the treatment effects in year $k = 1$ post-death; long-run effects refer to the average treatment effects in years $k = 1$ through $k = 5$. Covariates that are included as interactions with treatment status are also included as baseline effects, i.e., as an interaction of the baseline period effect $1(\text{period}_k)$ with the covariate. Same Occupation and Other Occupation are dummy variables indicating whether an incumbent worker was in the same 1-digit occupation group as the deceased or in a different occupation in the year before a worker death. Low-, medium-, and high-skilled occupations are indicators for the skill intensity of the deceased's 5-digit occupation as measured by the average years of education of workers in the occupation. Low-, medium-, and high-skilled occupations are defined as occupations below the 20th percentile, between the 20th and 80th percentile, and above the 80th percentile of average years of education, respectively. Low, medium, and high education indicate the education level of the deceased worker: low education - less than apprenticeship training, medium education - apprenticeship training, and high education - formal education beyond apprenticeship training. We measure the managerial status of the deceased's occupation as proxied by occupations requiring "complex specialist activities" (requirement level 3) or "highly complex activities" (requirement level 4) based on the 2010 Classification of Occupations. These occupations are characterized by managerial, planning and control activities, such as operation and work scheduling, supply management, and quality control and assurance and typically require a qualification as master craftsperson, graduation from a professional academy, or university studies (see *Klassifikation der Berufe 2010, Band 1: Systematischer und alphabetischer Teil mit Erläuterungen, Bundesagentur für Arbeit*). Observations are weighted inversely by the number of incumbent workers at the firm of the deceased. Standard errors are clustered at the firm level.

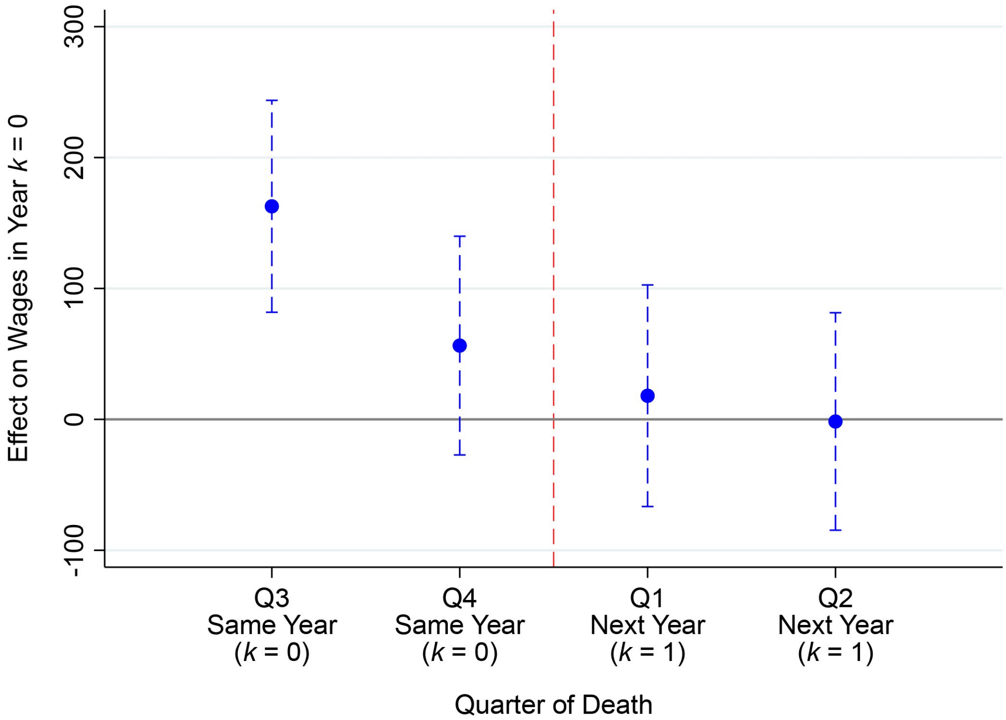
Figures

Figure A-4.1: Decomposition of Effects of Worker Death on Hiring



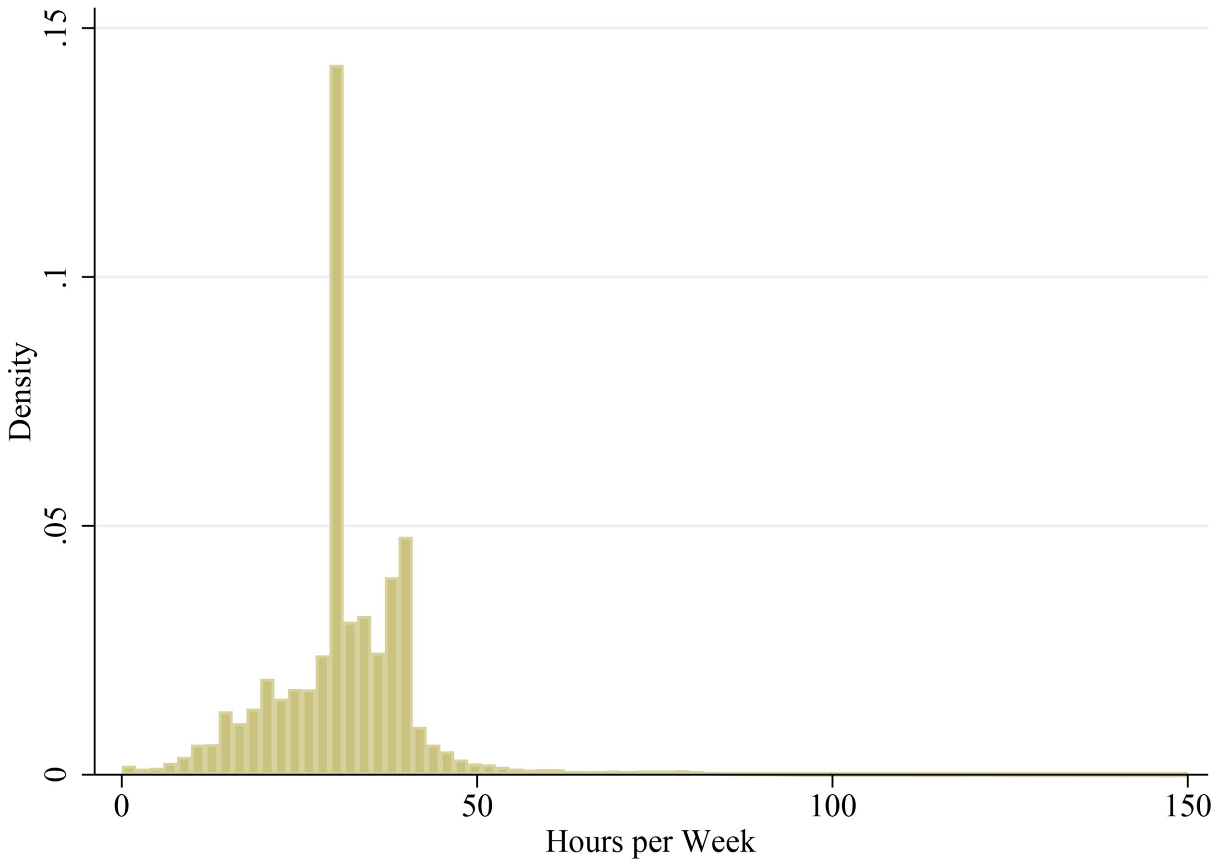
Note: The figure shows the treatment effect on hiring of new workers and decomposes the effect on total hiring (All New Hires) into hiring in the same 5-digit occupation as the deceased worker (Hires in Same Occupation) and hiring of workers into other occupations (Hires in Other Occupations). The treatment effect is normalized to zero in $k = -1$.
Source: Own calculations.

Figure A-4.2: Effects on Incumbent Worker Wages in Year $k = 0$ By Quarter of Death



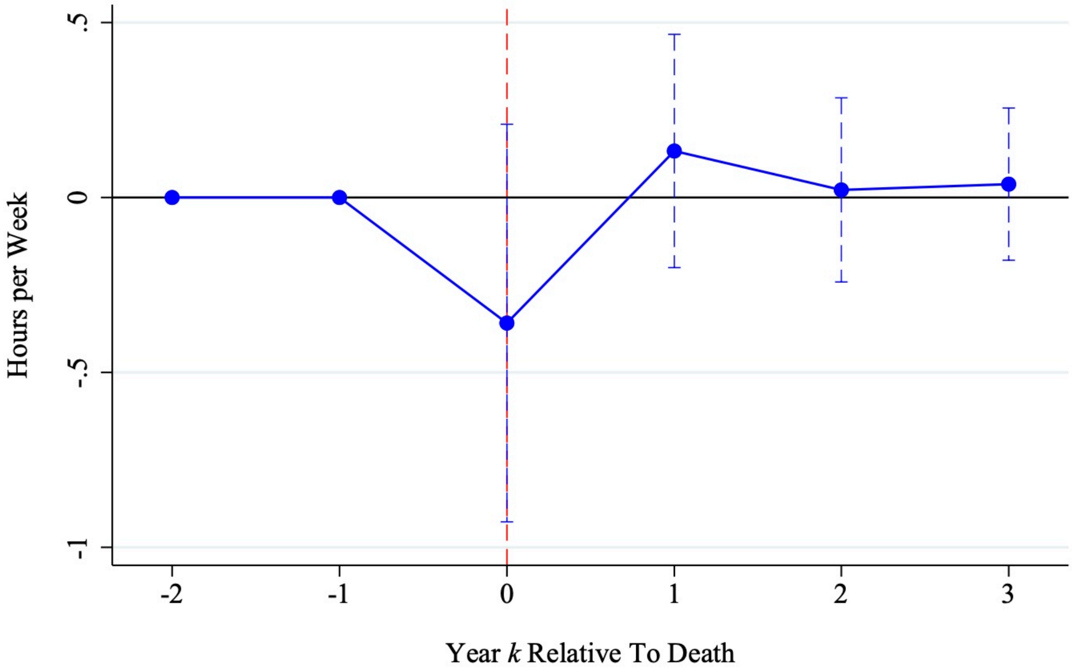
Note: The figure presents results of a difference-in-differences regression of wages in year k=0 on treatment status interacted with dummies for the quarter of death of the deceased worker in the treatment group. The positive and statistically significant coefficients for wage effects in year 0 of deaths that occur in Q3 (July, August, and September) document that the positive wage effects in year $k = 0$ (see, e.g., Figure 2) are driven by deaths that occur in the same calendar year, as wages for most workers correspond to average wages calculated over a calendar year horizon so that deaths in, e.g., August will have an effect on average wages in that year. The figure also demonstrates that deaths in the first quarter of the following calendar year do not have a statistically detectable effect on incumbent worker wages in the previous calendar year. Vertical lines denote 95% confidence intervals. See also Table A-4.9.
Source: Own calculations.

Figure A-4.3: Distribution of Hours Per Week



Note: The figure shows a histogram of hours per week based on administrative data from the German Statutory Accident Insurance, which required all firms to report information on workers' hours of work as part of their administrative reporting processes in the time period from 2010 to 2015. We drop outlier observations below the 1st and above the 99th percentile.
Source: Own calculations.

Figure A-4.4: Effect of Worker Deaths on Incumbent Worker Hours



Note: The figure displays regression coefficients and associated 95% confidence intervals for the difference between incumbent worker in the treatment and comparison group, i.e., the $\beta_k^{Treated}$ from equation (2). The coefficients in $k = -1$ are normalized to zero. The outcome variable are the reported hours per week of incumbent workers. Incumbent workers are defined as full-time coworkers of the deceased or placebo deceased in the year before death. The data on hours per week stem from administrative data from the German Statutory Accident Insurance, which required all firms to report information on workers' hours of work as part of their administrative reporting processes in the time period from 2010 to 2015. We drop outlier observations below the 1st and above the 99th percentile of hours per week.
Source: Own calculations.

List of Figures

List of Tables

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