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Abstract

We estimate how exogenous worker exits affect firms' demand for incumbent workers and new hires. Drawing on administrative data from Germany, we analyze 34,000 unexpected worker deaths, which, on average, raise the remaining workers' wages and retention probabilities. The average effect masks substantial heterogeneity: Coworkers in the same occupation as the deceased see positive wage effects; coworkers in other occupations experience wage decreases when a high-skilled or specialized worker dies. Our findings imply substantial replacement costs, which are larger in thin markets and when skills are specialized.

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1 Introduction

The fluidity of labor markets depends on the ease with which the two sides of the market can switch trading partners: workers finding alternative employment suitable for their skills and firms finding adequate substitutes for their current workers. An extensive body of empirical literature sheds light on the workers' perspective and finds that workers who are displaced from their jobs suffer persistent earnings losses—consistent with the presence of rents and with Becker's 1962 idea that human capital has firm-specific components (Jacobson, LaLonde, and Sullivan, 1993; Lazear, 2009). However, much less is known about the other side of the market: firms' ability to find substitutes for their workers, in particular ones with specific human capital. When a worker leaves a firm, how easily can the firm replace the worker externally through hiring, and how do such worker exits affect the firm's demand for its remaining workers? Several debates—ranging from the role of replacement costs (Slichter, 1919; Oi, 1962; Manning, 2011) and the mechanisms underlying rent sharing (Kline et al., 2019) to the importance of labor pooling as a source of agglomeration (Marshall, 1890)—hinge directly on the answer to this question.

We offer an empirical answer to this question by estimating the effects of exogenous worker exits on hiring, and on the firm's demand for the labor of the remaining incumbent workers. In a frictionless, competitive model, worker exits do not affect the firm's demand for incumbent workers: the firm can simply hire a suitable new worker in response to a worker exit. In contrast, when outsiders are only imperfect substitutes for insiders—for instance because the replacement of workers is costly—worker exits can affect the firm's labor demand for incumbent workers.

Our empirical answer leverages a quasi-experimental research design to estimate the causal effect of unexpected worker deaths on hiring and on incumbent workers' wages and retention rates based on the universe of German Social Security records. In a dynamic difference-in-differences design, we compare roughly 34,000 small firms that experienced the death of a worker in a given year to a comparison group of firms with similar characteristics which did not experience a worker death that year. The research design relies on deaths as a source of variation to circumvent the endogeneity of worker exits.[1] The sample excludes the deaths of workers who experienced a hospitalization or longer sickness spell in the five years before their death in order to exclude deaths preceded by debilitating diseases. The outcomes in the treatment and comparison group follow parallel trends in the years prior to the death of

[1]The use of deaths as a source of variation builds on previous work in Jones and Olken (2005); Bennedsen, Perez-Gonzalez, and Wolfenzon (2020); Bennedsen et al. (2007); Azoulay, Wang, and Zivin (2010); Oettl (2012);Becker and Hvide (2021); Isen (2013); Jaravel, Petkova, and Bell (2018); and Fadlon and Nielsen (2019).

a worker in treatment group firms, suggesting that outcomes in comparison group firms can be used to gauge what would have happened to treatment group firms in the absence of a worker death.

Based on almost 7 million worker-year observations, we show that worker deaths affect firms' demand for the labor of their remaining workers. On average, incumbent workers in the treatment group experience a statistically significant earnings increase of about 0.6% in the year after the death. Over the course of the five years after the death, the average cumulative effect on the earnings of all incumbent workers in a treatment group firm is close to €3,300 (2010 CPI), corresponding to about 13% of an average deceased worker's annual earnings. Moreover, incumbent workers in the treatment group are more likely to retain employment at the same firm and are less likely to be employed at other firms; their probability of (any) employment does not change in response to a worker death.

We document substantial heterogeneity in the effects across skill groups, occupational boundaries, and labor markets. Positive wage effects of worker exits are concentrated among incumbent workers in the same occupation group as the deceased. For deaths of managers and workers in high-skilled or specialized occupations, we estimate negative effects on the wages of incumbent workers in other occupations. Overall, effects of worker deaths are larger in magnitude for exits of workers with more specific human capital, e.g., with longer tenure or from more specialized occupations. Further corroborating the role of specialized skills, we also find larger effects on incumbent wages when the external labor market is thin in the deceased's occupation, i.e. when the local labor market's relative share of workers in the deceased's occupation is low. This difference is driven by deaths of workers in specialized occupations.

Since the evidence indicates that worker exits affect firms' demand for incumbents, our findings are hard to reconcile with frictionless labor markets and perfect substitutability between incumbents and outsiders. To quantify the deviation from a frictionless labor market, we draw on a simple wage posting model (Kline et al., 2019) with imperfect substitutability of incumbent workers and new hires and extend it to incorporate dynamics and multiple worker types. As in Becker (1964), firms in the model share rents with incumbent workers who are hard to replace, e.g., due to hiring and training costs. Following the intuition we describe above, firms will respond to the exit of a worker by increasing pay for incumbent workers to increase their retention only if worker replacement is costly. If markets are frictionless, firms respond only on the hiring margin. We estimate the model with the method of simulated moments to pick parameter values such that the model closely matches our reduced-form moments.

We find that firms in our sample face substantial replacement costs on an order of magnitude of about two annual salaries of a deceased worker. Our estimates further indicate that replacement costs are convex: the marginal cost of hiring an additional worker increases in the hiring rate. Interpreting the effect heterogeneity through the lens of the model indicates higher replacement costs for workers in thin labor markets.

While our estimation of replacement costs draws on a model with wage posting, we also assess several other models that could account for our reduced-form findings and probe alternative interpretations of our findings. First, we find qualitatively similar predictions in a multi-worker bargaining model (Stole and Zwiebel, 1996a,b; Cahuc, Marque, and Wasmer, 2008) or when we extend the Kline et al. (2019) model to incorporate bargaining. Second, we interpret our results through the lens of an internal labor market model with promotions (Doeringer and Piore, 1971; Baker, Gibbs, and Holmstrom, 1994a). The model we estimate could nest an internal labor market interpretation if promotions are simply labels for wage increases. However, wage increases in response to a worker exit might also reflect a chain of promotions of the remaining workers to fill the shoes of the worker who exited, irrespective of replacement costs. We test several predictions of this view. For example, we test whether wage increases are concentrated among workers ranking below the deceased worker but find, if anything, larger long-run wage effects for workers ranking above the deceased in the salary distribution. We conclude that our results are consistent with some internal labor market models, but are harder to reconcile with models of slot constraints and vacancy chains as important drivers of the effects we document.

We also assess the extent to which compensating differentials or changes in work hours can account for our findings. Incumbent worker wages may have gone up as a result of a worker death increasing the compensating differential for working at the firm, e.g., due to decreased utility of interacting with colleagues or increases in the perception of job hazards. While such purely labor supply-driven explanations could explain why wages increase, they would simultaneously predict that workers' probability of staying with the firm should decrease. The data, however, speak against this explanation, as both wages and the probability of staying at the firm go up. Therefore, positive shifts in firms' labor demand dominate any negative shocks to incumbent workers' labor supply. We also conduct other robustness checks, e.g., studying deaths on weekends, and find similar results in this subsample. We also study the extent to which hours changes could account for our findings, for example, if workers increase work hours after a coworker's death. We find no effect on changes from full- to part-time work, and also do not detect significant changes in hours. However, our analysis of hours is limited to a short sample period and overtime may only be imperfectly captured in this sample. To complement our analysis, we thus extend the Kline et al. (2019) analysis to incorporate an intensive margin and estimate it under the assumption that some of the wage earnings changes we document may reflect hours changes. Our results indicate that even with such intensive margin changes, firms face substantial costs of replacing workers on the order of magnitude of an incumbent's annual salary.

Our paper contributes to several additional strands of the literature. First, we quantify a core determinant of labor demand and wages: the frictions that firms face in replacing workers. Existing evidence, frequently drawn from surveys of firms' recruitment, hiring, and training costs, typically finds hiring and training costs on the order of magnitude of one month of workers' pay (see Hamermesh, 1996; Manning, 2011, for surveys). However, previous work has pointed out that such low hiring or replacement costs are hard to reconcile with the documented large costs of job loss to workers (Davis and von Wachter, 2011; Hall, 2011), and that larger post-match turnover costs (Silva and Toledo, 2009) or imperfect substitutability between new hires and incumbent workers (Mercan, Schoefer, and Sedláček, forthcoming) can generate more realistic volatility of vacancies and unemployment. Our estimates point to substantially larger estimates than what is implied by surveys and thereby help to alleviate these tensions. An additional difference between our revealed-preference approach and existing work is that it also captures the additional costs of retaining coworkers in response to a worker exit as well as the costs associated with losing an incumbent worker with high human capital or match specificity. Second, our paper complements the extensive literature on rent-sharing (see Card et al., 2018; Jäger et al., 2020, for overviews) by providing direct evidence for a mechanism—human capital specificity leading to imperfect substitutability between insiders and outsiders—that gives rise to such rent sharing. Moreover, low replacement costs are also hard to square with existing rent sharing estimates (see, e.g., Kline et al., 2019, 2021). Third, our finding of local labor market thickness associated with lower replacement costs provide direct evidence for the importance of labor pooling as an agglomeration force, especially in the context of specialized labor (Moretti, 2011). Our findings also inform the policy debate around skilled labor shortages (Sauer and Wollmershäuser, 2021; Causa et al., 2022) and highlight the costs of employee turnover and the association of market thickness with lower replacement costs. Fourth, our findings of imperfect substitutability inside the firm, e.g., across skill groups, provides firm-level evidence consistent with studies of how market-wide labor supply shocks, e.g., due to immigration or changes in the college graduation rate, affect the wage structure (see, e.g., Katz and Murphy, 1992; Card, 2009; Dustmann, Ludsteck, and Schönberg, 2009), and point to the important role of managerial human capital (Lucas, 1978; Rosen, 1982). Our analysis of worker deaths complements studies leveraging alternative identification strategies, e.g., the forced dismissal of researchers (Waldinger, 2012) or retirement reforms (Carta, D'Amuri, and von Wachter, 2021; Bianchi et al., 2022; Boeri, Garibaldi, and Moen, 2022).

2 Empirical Setting and Data

2.1 Empirical Setting: German Labor Market

To provide context for the following analysis, we briefly highlight several relevant characteristics of the German labor market. Our analysis of the effect of worker exits focuses on small firms. These are part of the so-called *Mittelstand*, small and medium-sized firms, which make up a large share of the German labor market. In our analysis, we focus on a sample of firms with less than 30 employees which account for about 30% of employment.

Relative to the OECD average, Germany has a relatively high manufacturing share at 22.6% of GDP (OECD: 15.0%, US: 12.7%, World Bank National Accounts Data, 2012). A key feature of the German education system is apprenticeship training offered by firms. As part of an apprenticeship training, a worker receives training in occupation- and industry-specific skills at a particular firm and a vocational school (see, e.g., Acemoglu, 1997; Acemoglu and Pischke, 1998).

The German labor market model combines sectoral bargaining between unions and employer associations at the industry-region level with institutions allowing for increasingly local wage-setting. Traditionally, collective bargaining agreements (CBAs) between employer associations and unions have played an important role in the wage setting process, although even historically less so in smaller firms (Ellguth and Kohaut, 2020). In the last decades, the wage setting processes in the German labor market have become increasingly decentralized (Hassel, 1999; Dustmann et al., 2014; Jäger, Noy, and Schoefer, forthcoming). While employers could always raise wages beyond CBA levels, opening and hardship clauses, which give firms more flexibility to negotiate with their workers directly and to pay below-CBA wages, have become increasingly common along with a lower overall coverage rate of collective bargaining agreements (Brändle, Heinbach, and Maier, 2011; Bispinck, Dribbusch, and Schulten, 2010; Ellguth and Kohaut, 2020).

2.2 Primary Data Source: Social Security Records

We use matched employer-employee data based on the universe of German Social Security records from 1975 until 2011. The data feature detailed information on all workers at an establishment, which allows us to measure how worker exits affect both the hiring of new workers as well as the wages of incumbent workers at the establishment. Two additional features of the dataset make it a compelling setting to assess the substitutability of workers. First, wages are directly reported as part of administrative procedures. Second, the dataset is large covering all employment subject to Social Security in Germany, which allows for a relatively precise estimation of effects and enables an analysis of wage effects for different types of firms and workers to shed light on the mechanisms driving the results. This is a key difference compared to many existing existing estimates of replacement costs, which often leverage surveys or personnel records from specific firms rather than administrative data. Based on the universe of German Social Security records, the dataset used for our analysis covers about 82% of employment in Germany (own calculations for 1981 to 2011 based on Mikrozensus). The key employment categories that are excluded are civil servants and the self-employed, as their employment is not subject to social insurance provided through the Social Security system.

The data stem from the Integrated Employment Biographies (IEB) database of the Institute for Employment Research (IAB). As part of its administrative processes, the German Social Security system collects data from employers on all employees in jobs subject to Social Security taxation. The data that employers mandatorily need to report for each employee include the start and end date of each job, the employee's earnings up to the censoring limit at the maximum taxable earnings level, and data on education levels, apprenticeship status, and occupation as well as basic demographic information like gender, birth date and citizenship. The frequency of reporting is typically once per year and, in addition, whenever a new employment spell starts or ends or the job status changes, e.g., from part-time to full-time employment.

We use data on workers' daily earnings as the primary outcome variable. The earnings variable reports gross earnings, which are reported as daily earnings associated with a specific employment spell. For the analysis, we scale up daily earnings by a factor of 365 to correspond to yearly earnings and deflate all reported earnings to correspond to the 2010 CPI. The main dataset does not contain information on the exact hours worked, but does contain information on whether employment is full- or part-time. For full-time workers, the reported earnings likely corresponds closely to the wage due to limited variation in working hours. We follow the existing literature using this data source (see, e.g., Dustmann, Ludsteck, and Schönberg, 2009; Card, Heining, and Kline, 2013) and use the terms earnings and wages interchangeably. In our analysis, we also assess whether hours of work are affected at the part-time versus full-time margin, draw on novel data on hours worked reported by the Statutory Accident Insurance from 2010 to 2015, and also estimate a model assuming that earnings responses may, at least partially, reflect hours changes.

A drawback of the earnings data is that—as in many administrative datasets—earnings are top-coded above the Social Security earnings maximum. For example, in 2011, the earnings maximum was at €66,000 for West Germany, corresponding to about US$ 88,200 at the time. The average earnings of deceased and incumbent workers in our sample is around €27,000, i.e., about half of the 2011 earnings maximum. In the sample we work with, 6.0% of earnings observations are censored. As our analysis focuses primarily on within-worker and within-establishment variation in wages, imputation procedures based on lagged or current individual or employer-level information would not add additional information for the analysis. We therefore do not impute earnings above the Social Security earnings maximum, and instead set wages to the earnings maximum if they are top-coded. Our analysis thus does not capture variation in wages above the earnings maximum. Excluding workers with initial earnings at or above the maximum leads to effect sizes on wages about 5% larger than without this restriction. Another drawback is that we do not have access to suitable data on revenue or productivity.[2]

To assess the interdependencies between workers inside the firm and understand heterogeneity in the effect of worker exits, we leverage detailed data on the deceased workers' and the remaining incumbent workers' occupations. Workers' occupations are reported at the 5-digit level of the 2010 Classification of Occupations and its predecessors (Klassifikation der Berufe 2010, see Paulus and Matthes, 2013, for an overview). Occupations are classified primarily along two dimensions: first, horizontally into occupation groups based on the thematic focus of the work, e.g., production and manufacturing vs. accounting. We then use this horizontal classification to identify groups of workers inside a firm who work in jobs with a similar or distinct thematic focus (1-digit occupation). Second, occupations are classified vertically based on the skill requirements of the occupation. We use this vertical categorization to identify workers in managerial and supervisory roles.[3]

Our analysis focuses on wage effects as well as hiring and employment at the establishment level. The Social Security system assigns unique establishment IDs based on ownership, industry, and location at the municipality level.[4] The assignment of establishment IDs implies, for example, that two bakeries operated by the same firm in the same city would be reported as one establishment. In contrast, a bakery and a mill operated by the same firm would be classified as different establishments even when they are located in the same municipality. In

[2] We do not draw on firm-level data on revenue or productivity, e.g., from the IAB Establishment Panel or Orbis-ADIAB, due to an insufficient sample size of establishments in the size category we study.

[3] We classify workers as managers if they work in an occupation requiring "complex specialist activities" (requirement level 3) or "highly complex activities" (requirement level 4). These occupations are characterized by managerial, planning and control activities, such as operation and work scheduling, supply management, and quality control and assurance. They typically require a qualification as master craftsperson, graduation from a professional academy, or university studies (see Bundesagentur für Arbeit (2011)).

[4] The Social Security system issues a new establishment ID after an ownership change and other reorganizations. Hethey-Maier and Schmieder (2013) use a worker flow methodology to document that only about 35 to 40% of new or disappearing establishment IDs in the German Social Security data correspond to actual establishment entries or exits. Due to the uncertainty surrounding the continued operation of an establishment when the establishment ID disappeared, we focus on a balanced panel of establishments with a consistent establishment ID so that the analysis follows a well-defined economic unit that is consistent over time.

all cases, our analysis will be conducted at a within-firm level and all coworkers will be employed by the same firm. The analysis may not capture all employment at a firm in the case of multi-establishment firms. However, for the sample that we consider, an estimated 84% of establishments correspond to single-establishment firms (Antoni, Laible, and Schild, 2015). In keeping with convention (Dustmann, Ludsteck, and Schönberg, 2009; Card, Heining, and Kline, 2013)), we will use the terms establishment and firm interchangeably throughout.

3 Empirical Strategy

3.1 Identifying Unexpected Deaths in Social Security Data

To circumvent the endogeneity of worker exits from a firm, we leverage deaths of workers as a source of variation in a firm's labor supply. We identify deaths based on employer notifications to the Social Security system and restrict the analysis to deaths of workers who are younger than 65 at the time of death and who did not experience a hospitalization or a longer sickness spell in the five years before their death.

The employer needs to notify the Social Security system when an employment spell ends. If an employment spell ends because an employee died, the notification states that the ending of the spell was due to the death of the employee. Death notifications are available from 1980 onwards. We identify deaths in the Social Security data and verify that the death reports are not spurious: for more than 93% of reported deaths, the reported death date corresponds to the latest date for which an employment or unemployment spell is reported in the data. Most of the remaining observations with spells with end dates after the reported death date end within weeks after death, suggesting that in these cases there are some minor inconsistencies in the exact date of reporting. To rule out spurious death notifications, we restrict our analysis to reported deaths with no spell endings more than 30 days after the first reported death date, which comprise more than 97% of reported deaths.

We focus on deaths that are arguably premature and unexpected. First, we restrict the sample to deaths of individuals who are younger than 65 at the time of death. Second, we focus on individuals who were employed full-time at the time of death. Third, to rule out deaths that were preceded by a debilitating disease, we drop the 42% of employer-reported deaths with a sickness leave in the five years before. The Social Insurance system pays sickness or wage replacement benefits during hospitalizations—of any duration—as well as during sickness leaves of six weeks or more. (Shorter sickness leaves are mandatorily covered by employers and are typically not observed in the data.) Receipt of wage replacement benefits is reported in the data, which allows us to restrict the sample to individuals who did not experience a hospitalization or longer sickness leave before their death.[5] So even though the cause of death is not reported in the data, the additional restrictions lead to the exclusion of deaths that are caused by slow-moving, debilitating diseases, such as many cancers, but do include unanticipated deaths, such as those due to accidents or strokes.

3.2 Matched Sampling Procedure to Select Comparison Group

A key challenge is to find an appropriate comparison group for firms that experience the death of an employee. We use a matched sampling procedure—similar to the approach in Azoulay, Wang, and Zivin (2010)—to identify a comparison group of placebo deceased worker-firm pairs in which the worker did not die but that have lagged characteristics similar to the ones of treatment group worker-firm pairs in which the worker died.

Time Notation. We let t denote calendar years, d event (death) years, and $k = t - d$ the year relative to an event. For a given year t, we measure outcomes on July 1 of that year. A death is defined to occur in event year d if it occurs between July 1 of d and June 30 of $d + 1$ so that a death occurs between $k = 0$ and $k = 1$.

Treatment Group. For each event year d from 1980 to 2007, we identify the set of worker deaths in d for whom the restrictions described in 3.1 are met. Death notifications are reported from 1980 onwards and we require a sufficiently long post-death period. For each worker who died in d and for their employer at the time of death, we record a rich set of baseline characteristics in $d - 4$, i.e., four years before death.

Pool for Comparison Group. For each event year d, the comparison group is sampled from the set of worker-firm pairs in firms which did not experience the death of an employee in d. Analogous to the procedure for the treatment group, we record baseline characteristics in $d - 4$ for this comparison group pool.

Matched Sampling to Select Comparison Group. We implement a matched sampling procedure separately for each event year d. For each deceased worker-firm pair in the treatment group, we select a worker-firm pair from the comparison group pool with similar lagged characteristics. This approach is motivated by Rosenbaum and Rubin (1985) and Imbens and Rubin (2015, chapter 15), who describe how matched sampling can be used to find a comparison group of similar size and with similar observed characteristics as the treatment group and follows the precedent in the literature (Azoulay, Wang, and Zivin, 2010). In each event year d, we select placebo deceased worker-firm pairs from the comparison group

[5] The data do not distinguish between the different kinds of wage replacement benefits ("Entgeltersatzleistungen") which also include maternity benefits. As we exclude individuals who received any kind of wage replacement benefits, the restriction will also exclude some individuals who received maternity benefits in the five years before death.

pool of worker-firm pairs that did not experience a death in d to match exactly the following characteristics of actual deceased worker-firm pairs in the treatment group:

- Worker characteristics: age in years, gender, education group (i) no apprenticeship training (low), (ii) workers with an apprenticeship training (medium), and (iii) workers with a qualification for university studies (*Abitur*) or a university-level education (high)], deciles of earnings in $d-4$

- Firm characteristics: number of employees in $d-4$, deciles of average earnings at the firm in $d-4$.

These variables are chosen to create a comparison group with similar observed characteristics as the treatment group, in particular age and gender, as deceased workers in the sample are on average 7.4 years older and more likely to be male than workers in the pool for the comparison group (86% vs. 62% men). An exact match is found for 95.81% of worker-firm pairs in the treatment group. When no exact match can be found, i.e., in the remaining 4.19% of cases, the deceased worker-firm pair is not included in the sample. When multiple potential matches for a deceased worker-firm pair are available, we select the unit from the comparison group pool with the closest propensity score calculated based on a rich set of worker-and firm-level covariates.[6]

The matched sampling procedure implies that the comparison between the treatment and the comparison group is between coworkers and establishments of actual and placebo deceased workers with the same year of birth and the same age at—actual or placebo—death and, moreover, the same gender and earnings. Importantly, we do not match on trends—only on lagged covariates in $d-4$—so that the pre-trends themselves can be used to evaluate the plausibility of the common trends assumption.

Sample Restrictions. In both the treatment and the comparison group, we restrict the sample to employers with between 3 and 30 full-time employees four years before death, which comprise about 30.5% of employment subject to Social Security in Germany.[7] There are two key reasons for focusing on smaller establishments. First, in larger establishments worker exits due to death occur more frequently due to the law of large numbers, thus preventing an analysis of sharp shocks. Second, the effect of a worker death on average

[6]The propensity score is calculated based on a linear probability model that includes linearly the average wage at the establishment and the individual wage of the worker, tenure and occupation experience, dummies for the number of full-time workers at the establishment and the age of the establishment, as well as fixed effects for industry (3 digit) and occupation (5 digit) in addition to the variables used for the exact matching. All characteristics are measured in $d-4$. In each event year, a firm is sampled at most once from the comparison group pool, but firms can be sampled multiple times across years.

[7]A cutoff of 30 employees is a common legal threshold to distinguish small employers from larger ones (see, e.g., Act on the Compensation of Employer Expenditures (*Aufwendungsausgleichsgesetz*).

coworker wages decreases with firm size so that it will be hard to detect in larger firms. We drop establishments that are part of the government or the social insurance system, churches and other non-profits (industry code larger than 870 in the 1973 edition of the German Classification of Economic Activities), and keep establishments in the service, manufacturing and agricultural sector. Finally, we exclude firms with multiple worker deaths in a given year to rule out deaths due to larger disasters that may have independent effects on outcomes and focus on a balanced panel of firms. In both the treatment and the comparison group, we require that the—actual or placebo—deceased was employed full-time in d and in $d - 4$, thereby restricting the sample to individuals with high labor force attachment. To include workers with short tenure in our analysis, we do not condition on employment at the *same* firm in the years before d, only on full-time employment at any firm in d and in $d - 4$.

3.3 Summary Statistics

This section provides summary statistics for workers and firms in the treatment and comparison group to assess to what extent the matched sampling created a balanced comparison group for the difference-in-differences design and provide context for the interpretation of treatment effects. (Our difference-in-differences design permits differences in average levels of outcome variables between the treatment and comparison group and instead relies on a common trend assumption.)

Characteristics of Actual and Placebo Deceased Workers. Columns (1) and (2) of Table 1 report summary statistics for the 33,786 actual and the same number of placebo deceased workers in the treatment and comparison group, respectively, in the year before the worker death. The average deceased worked is 47 years old and overwhelmingly male (86%) with 10.6 years of education, corresponding approximately to an apprenticeship training—the most common educational credential in Germany. In the year before death, actual and placebo deceased workers earned a wage corresponding to an annual salary of €26,099 in the treatment and €26,413 in the comparison group, respectively. Both groups of workers have an average tenure of about 9.5 years at the firm. The similarity between actual and placebo deceased workers is not a mechanical effect of the matched sampling, as the matching relied on variables in $k = -4$.

Characteristics of Incumbent Workers in Treatment and Comparison Group. In order to gauge the effects of worker exits on firms' labor demand for the remaining workers, we define a sample of incumbent workers as the set of full-time coworkers of the deceased in event year d.[8] Columns (3) and (4) of Table 1 report summary statistics for these incumbent

[8]Similar to the sample restriction for the actual and placebo deceased workers, we restrict this sample

workers who are slightly younger than the actual and placebo deceased workers with an average age of 39 and are more likely to be female (26%). Incumbent workers have average earnings in $k = -1$ of about €28,000 (€27,770 in the treatment, €27,840 in the comparison group), an average level of education of 10.9 years, and have about 7 years of tenure with the establishment.

Characteristics of Firms in Treatment and Comparison Group. We report summary statistics for the firms in the treatment and comparison group in Table 2 in the year before the worker death. The average establishment in the treatment group has 14.45 employees (14.51 in the comparison group), of which about 15% are new employees, and has been observed in the data for about 14.8 years. About 3% of firms are in the primary sector (agriculture, mining), 50% in the secondary sector (manufacturing), and 47% in the tertiary sector (services). Since we do not match exactly on industry, occupation of the deceased, and the location of the firm, a potential concern could be that there is substantial imbalance in these dimensions. We assess this concern by regressing treatment status on industry fixed effects (3 digit), fixed effects for the occupation of the deceased (5 digit), and labor market region fixed effects (50 regions based on Kropp and Schwengler, 2011) and find that these variables are jointly insignificant in predicting treatment status in our sample ($p = 0.336$).

3.4 Estimating Equations and Identification

Estimating Equations for Firm-Level Outcomes. We estimate the effect of a worker death on hiring and employment based on the following dynamic difference-in-differences framework:

$$y_{jk} = \alpha + \gamma_j + \sum_{k=-3}^{5} \beta_k \times \mathbb{1}(\text{period}_k) + \sum_{k=-3}^{5} \beta_k^{Treated} \times \mathbb{1}(\text{period}_k) \times \text{Treated}_j + \epsilon_{jk}, \quad (1)$$

where y_{jk} denotes the outcome y for firm j in year $k = t - d$ relative to the worker death occurring in year d. The model includes firm fixed effects, γ_j, and leads and lags around event time, $\mathbb{1}(\text{period}_k)$.[9] Treated_j is an indicator function for treatment status. The coefficients of

to incumbent workers younger than 65 in $k = -1$. Incumbent workers remain in the sample regardless of whether they remain at the firm in subsequent periods. In case of non-employment in a given year, we set their earnings to zero. In Table A-4.3 in the Appendix, we also report results for two additional groups of incumbents: the sample of part-time coworkers and individuals who were apprentices.

[9] Formally, we consider firms sampled in different event years as different firms, leading to a finer set of fixed effects. For example, if firm A is sampled in event year $d = 1985$ and in event year $d = 1991$, the model includes separate fixed effects for A_{1985} and A_{1991} which are finer and subsume a fixed effect for A only. The model in (1) does not include calendar year fixed effects as calendar time is balanced between the comparison and treatment group as a consequence of the matched sampling procedure which we implement separately for each event year d. We have also run all specifications allowing for calendar year fixed effects which, mechanically, does not change the point estimates of the treatment effects and, in addition, leads to very similar standard errors.

interest, $\beta_k^{Treated}$, capture the effect of an actual worker death in year $k = t - d$ in the treatment group and are normalized to zero in $k = -1$ ($\beta_{-1}^{Treated} = 0$). We define the *short-run treatment effect* as the effect in the first post-death year, $\beta_1^{Treated}$, and a *long-run treatment effect* as the average of treatment effects in the five-year post-period, $\frac{1}{5}\sum_{k=1}^{5}\beta_k^{Treated}$. We cluster standard errors at the firm level. While treatment varies at the finer firm by year-relative-to-death level, clustering at the firm level addresses potential concerns of serial correlation of outcomes across periods (Bertrand, Duflo, and Mullainathan, 2004).

The model allows for average differences between the treatment and the comparison group as they are absorbed by the firm fixed effects, γ_j, so we do not assume that the treatment and comparison group would have the same average outcomes in the absence of treatment. Rather, the variation we leverage for identification occurs within the same firm, comparing outcomes relative to $k = -1$, and within the same time k relative to the actual or placebo worker death, comparing treatment group firms to firms in the comparison group.

Estimating Equations for Incumbent Worker Outcomes. The estimating equation in (1) above describes specifications to estimate treatment effects on firm-level outcomes such as employment and hiring. To analyze treatment effects on outcomes for incumbent workers, e.g., wages, we estimate very similar difference-in-differences specifications on the sample of incumbent workers, defined as the set of full-time coworkers of the deceased in event year d. Individuals remain in the incumbent worker sample if they were coworkers of the deceased in d regardless of whether they remain at the same firm in subsequent years, as the probability of retainment could itself be affected by a worker death.

We use the following difference-in-differences framework to estimate treatment effects on incumbent workers:

$$y_{ijk} = \alpha + \gamma_{ij} + \sum_{k=-3}^{5}\beta_k \times \mathbb{1}(\text{period}_k) + \sum_{k=-3}^{5}\beta_k^{Treated} \times \mathbb{1}(\text{period}_k) \times \text{Treated}_{ij} + \epsilon_{ijk}. \quad (2)$$

Here, y_{ijk} denotes the outcome y for incumbent worker i at firm j in year $k = t - d$ relative to the worker death occurring in year d. The model includes incumbent worker-firm effects that absorb unobserved heterogeneity across incumbent workers. As before, the model includes leads and lags around event time, $\mathbb{1}(\text{period}_k)$, and the coefficients of interest are the $\beta_k^{Treated}$. The model is estimated as a weighted regression in which each incumbent-worker observation is weighted by the inverse of the total number of incumbent workers at a firm in d so that all worker deaths have equal weight and treatment effects can be readily compared between specifications (1) and (2). As before, standard errors are clustered at the firm level. Short-run and average long-run treatment effects are also defined analogously as $\beta_1^{Treated}$ and $\frac{1}{5}\sum_{k=1}^{5}\beta_k^{Treated}$, respectively. Finally, the identification assumption also remains the same and requires that worker deaths are exogenous conditional on the covariates included in the model.

Identification Assumption and Potential Threats to Identification. The key assumption for identification is that worker deaths are exogenous conditional on the covariates included in the model. This implies that firms in the treatment and the comparison group would have followed parallel trends in $k > 0$ if, counterfactually, no worker death had occurred in the treatment group. Since firms are observed in periods before the actual or placebo worker death occurs, the plausibility of this assumption can be tested by assessing whether outcomes follow parallel trends in the treatment and comparison group in the pre-period.

Potential threats to identification would be the existence of contemporaneous shocks that affect outcomes and also the timing of deaths in the treatment group. Given that the estimated effects on coworker wages are on average positive, a potential threat to identification arises, e.g., if deaths of workers reflect additional stress from an uptick in firm performance that results in higher wages. Alternatively, the positive estimates could be downward-biased if deaths occur as a consequence of negative shocks to the firm. However, when pre-trends are parallel, such shocks would have to be sudden in onset but, at the same time, large enough to be associated with worker deaths. This, in turn, makes some potential threats to identification less compelling: coronary heart disease, for instance, develops over a long time span and is caused by chronic rather than short-term stress levels (Kivimäki et al., 2006).[10]

In addition to analyzing pre-trends, we implement a further test to gauge the importance of these potential challenges to identification, and document that firms in the treatment group do not have a higher propensity of experiencing a worker death in future periods, $k > 0$, relative to the comparison group. Unobserved shocks that are sudden in onset could be hard to detect in the pre-period but could affect mortality and outcomes in future periods, thereby leading to a bias in the estimate of the treatment effect. If that were the case, one would expect to see an increased propensity of firms in the treatment group to experience worker deaths in $k > 0$. We test this hypothesis by regressing an indicator for whether a firm experienced a worker death in a given future period, $k > 0$, on treatment status. Appendix Table A-4.1 reveals that firms in the treatment and comparison group have an identical probability (about 1.2%) of experiencing a worker death in a given future period, as the indicator for treatment status is statistically insignificant and small. As firms in the treatment group do not have a higher propensity to experience future worker deaths it appears that the worker deaths under study are indeed idiosyncratic shocks to the labor

[10]In a meta-analysis of the effects of work stress on coronary heart disease, Kivimäki et al. (2006) summarize the short- and long-term effects of work-related stress on coronary heart disease (CHD) as follows: "All studies with null findings assessed job strain at one point in time only. As CHD develops over a long time span, long-term rather than short-term levels of job strain are assumed to have an impact on CHD incidence."

supply of firms in the treatment group.

Heterogeneity of Treatment Effects. In order to assess heterogeneity in the treatment effects, we estimate variations of the econometric models in (1) and (2) that include interactions between the post-period treatment effects, i.e., the interaction of $\mathbb{1}(\text{period}_k)$ and treatment status, and some covariates, e.g., the skill level of the deceased worker. Whenever such interaction terms are included, the model also includes a set of interactions of the baseline period effects, $\mathbb{1}(\text{period}_k)$, with the relevant covariates.

4 Effects of Worker Deaths on Employment, Hiring, and Coworker Wages

4.1 Effects of Worker Exits on Firm Employment and Hiring

In a first step, we document that a worker death constitutes a shock to a firm's labor supply and affects employment and hiring. Following a worker death, employment in treatment group firms is temporarily lowered. Hiring rises sharply and some hiring occurs in occupations other than the one of the deceased.

Figure 1a shows that worker deaths are a shock to the firm's labor supply. We show the effect on the probability of employment of the actual and placebo deceased worker at treatment and comparison group firms with a red dashed line. The trend in the pre-period is flat; there is a sharp drop after the death of the worker in the treatment group between $k = 0$ and $k = 1$. If there were no turnover of placebo deceased workers in the comparison group, the drop would equal -1. If turnover was so high that no worker remained with the same firm for more than a year, the drop would equal 0 as all placebo deceased workers in the comparison group would have left the firm after a year. In the data, the drop is closer to -1 at -0.866 (SE 0.0027) in the first post-death period and is equal to -0.565 after five years. Stated differently, the death of a worker is a sharp shock to a firm's labor supply that decreases in magnitude over time, as workers that do not die have a positive probability of leaving the firm over time.

The solid, blue series in Figure 1a documents that the shock to the labor supply of an individual worker due to death affects employment at the firm in the short-run. Employment drops by -0.340 (SE 0.035) workers in the first period after death. The gap is substantially smaller and indistinguishable from zero in the subsequent periods. If workers were immediately replaced externally, the effect in the first period would equal zero, as firms would hire a replacement worker instantaneously.

Figure 1b shows that hiring of new workers rises sharply following a worker death, but the magnitude of the effect on hiring is substantially smaller than a one-for-one external replacement. In the first post-death period, $k = 1$, firms hire on average 0.401 (SE 0.028) new workers and an additional 0.224 and 0.080 workers in the subsequent two periods. Figure A-4.1 decomposes the hiring effect into two components: the hiring of workers who work in the same 5-digit occupation as the deceased and hiring of workers in other occupations. About a quarter of the hiring response to worker exits is due to hiring in other occupations.

4.2 How Do Worker Exits Affect Incumbent Worker Wages and Employment Outcomes?

This section examines the average effects of worker exits on incumbents' wages and employment. Figure 2 documents the dynamics of the treatment effect on the earnings of incumbents (see also Appendix Table A-4.2). The upper panel uses individual incumbent workers' labor earnings as the outcome variable and documents a statistically significant increase of €173.40 (SE 37.47) in the first post-death period, $k = 1$. Compared to incumbent workers' average yearly earnings of €27,856 in $k = -1$, this corresponds to a real increase of about 0.6%. Wages of incumbent workers in the treatment group stay elevated for several years and remain statistically significant as long as the fourth post-death period, $k = 4$.

The lower panel of Figure 2 provides a similar picture based on a specification which uses the sum of earnings of all of the deceased worker's coworkers as the outcome variable. On average, the sum of coworker earnings increases by €1582.93 (SE 430.78) in the year following a worker death. The treatment effect then gradually decreases over time and remains statistically significant for the first two post-death periods. The total effect on the sum of coworker earnings in the first five post-death years is €3,288 so that the increase in incumbent worker earnings corresponds to about 13% of a deceased worker's average annual earnings (€26,099 in $k = -1$).

For both outcome variables, the pre-trends leading up to the worker death are small and statistically indistinguishable from zero which suggests that the outcomes in the comparison group can be used to gauge what would have happened in the treatment group had the worker death not occurred. As wages are reported as a yearly average for a typical worker, the outcomes in period $k = 0$ could be affected by a worker death which occurs between July 1 of $k = 0$ and June 30 of $k = 1$. Indeed, the treatment effects are statistically significant and positive in period $k = 0$ for both outcome variables. However, the nonzero effect in $k = 0$ is not a violation of the parallel trends assumption. The positive effect in $k = 0$ is entirely driven by worker deaths that occur in the same calendar year as wage measurement in $k = 0$ and is not affected by deaths that occur in the first half of the subsequent calendar year. In Appendix Figure A-4.2, we show incumbent wage effects in $k = 0$ and split the analysis by the calendar time quarter of death of the deceased worker. The results clearly document that the positive treatment effects in $k = 0$ are driven by deaths that occur in the third and fourth quarter of the same calendar year. In contrast, deaths that occur in the first two quarters of $k = 1$ are associated with substantially smaller and statistically insignificant wage effects in $k = 0$. The fact that deaths in the first quarters of the following calendar year do not have a statistically detectable effect on incumbent worker wages in the previous calendar year supports the parallel trends assumption and suggests that the worker deaths under study are unexpected even at a relatively short horizon.

In Table 3, we document treatment effects on several employment outcomes. First, turnover of incumbent workers in treatment group firms is lower: each incumbent worker has, on average, about a 0.3 percentage point higher probability of remaining employed at the same firm. Incumbents in the treatment group are, however, not more likely to be employed at all, as the long-run effect on full-time employment is zero.

The treatment effect on the probability of part-time employment is a precisely estimated zero. Even though our primary dataset does not contain fine-grained measures of working hours, the absence of an effect on part-time work status suggests that the intensive margin hours response may be limited. However, we also note that the base probability of switching to part-time work is low in our sample, thereby rendering the part-time/full-time margin overall less relevant. We revisit the evidence on intensive margin changes and how they change our interpretation of results in Section 6.4.

Effects Among Other Groups: Part-Time Incumbents, Apprentices, and New Hires. We also analyze the effects on outcomes of part-time workers and apprentices in Appendix Table A-4.3. For part-time incumbents, we find qualitatively similar results. Wage earnings increase by €159.66 (SE 83.47) in the short run, and we find a similar long-term effect (€150.70, SE 85.21). We find positive but statistically insignificant effects on the probability to remain employed at the same establishment or to switch into full-time employment. For apprentices, we find positive but statistically insignificant increases in earnings of around €118 per year as well as a sharp and statistically significant increase of 1.26ppt (SE 0.5ppt) to 1.49ppt (SE 0.4ppt) in the probability to remain employed at the same establishment.

We also study how a worker death affects wages and characteristics of new hires. In Appendix Table A-4.4, we document a large increase in new hires' wages of €1,201 in the first year and €490 in the long run. Taken at face value, these results would be consistent with a bargaining model or with some monopsony power in the market for new hires. This would contrast with the conclusions in Kline et al. (2019) and Garin, Silverio et al. (2018) who find no rent sharing among new workers. However, we caution that the effects on the wages of new hires are conceptually harder to interpret than the effects on wages of incumbents. That is, for the analysis of incumbents, we draw on a well-defined treatment and control group while for new hires the identity of the new hires potentially changes. Therefore, compositional changes in new hires' characteristics could explain at least some of the effects we document. Indeed, we find that characteristics of new hires change in response to a worker death. In Appendix Table A-4.5, we document that while education levels do not change on average, new hires are older and more experienced compared to the workers the firm would have hired in the absence of the worker death. Thus, they resemble the worker who passed away more closely than the cohorts of new workers the firm would have hired otherwise.

4.3 Heterogeneity Within And Across Occupations

We estimate the effect on wages of incumbent workers in the same occupation group as the deceased versus on incumbents in other occupation groups. We classify workers as being in the same or in other occupation groups based on their 1-digit occupation in the year before death. The 1-digit occupation groups classify occupations based on the broad thematic focus of the work, e.g., production and manufacturing vs. accounting. Figure 3 shows that the effect of a worker death on incumbent workers in the same occupation group as the deceased is statistically significant and positive at €239.17 in the short run and 148.11 in the long run (see Table 4). In contrast, the average effect on workers in other occupation groups is about 32% smaller and only statistically significant in the short run.

4.4 Heterogeneity by Workers' Skills

We next analyze heterogeneity in the effect depending on the deceased's skill levels to investigate whether workers with more or more specific skills might be harder to replace. We focus on three measures: (i) education levels, (ii) skill intensity of the occupation, and (iii) managerial or supervisory status. We then focus on two measures of specificity by studying heterogeneity in the deceased's tenure and a measure of human capital specificity of the deceased's occupation.

Education Levels and Occupational Skill Intensity As a first skill measure, we study heterogeneity in the deceased's education level and report results in Figure 4 Panel (b) and Table 5. We categorize education levels as low (no apprenticeship training), medium (apprenticeship training), or high (workers with a university entrance exam (*Abitur*) or a college degree). We find positive average effects in the low- and medium-education categories and negative average effects in the high-education category. Since the overwhelming majority of workers in our sample have an apprenticeship training (79.5%), the effects of deaths of workers in the low- and high-education group are imprecisely estimated. We also distinguish between effects within and across occupation boundaries, as in Section 4.3. The analysis reveals positive point estimates for low and medium education levels on coworkers in the same occupation as the deceased. Strikingly, we find large and negative effects of high-education worker deaths on workers in other occupations, with effects of -€521.38 (SE €272.43) in the short-run and -€273.86 (€301.98) in the long-run.

We also analyze heterogeneity based on the skill intensity of the deceased's occupation and report qualitatively similar results in Figure 4 Panel (a) and Table 5. We focus on the skill intensity of the occupation level, as the modal education level is an apprenticeship training and apprenticeship programs differ widely in the skill level of the targeted occupation. To measure the skill level of an occupation we calculate the average years of education at the 5-digit level based on a 20% sample of IEB biographies and then classify occupations as low- (below 20th percentile), as medium- (between 20th and 80th percentile), and high-skilled (above 80th percentile). Here, we find positive wage effects across the skill distribution of deceased workers on workers in the same occupation group as the deceased. Again, we find negative wage effects of workers in high-skill occupations on workers in other occupations, with a short-run effect of -€119.70 (€150.93) and a long-run effect of -€54.37 (€167.89).

Managerial Status As another dimension of skill, we explore heterogeneity in the deceased worker's managerial status and find that deaths of managers are associated with negative effects on the wages of incumbent workers in other occupation groups (see Figure 4 Panel (c) and Table 5). We classify workers as managers if they worked in an occupation characterized by managerial, planning and control activities, such as operation and work scheduling, supply management, and quality control and assurance.[11] Based on this distinction, we find that deaths of workers in non-manager occupations are associated with positive effects on incumbent wages across and within the deceased's occupation group as are deaths of managers on workes in other occupations. In contrast, the effect of manager deaths on incumbents in other occupations is negative at -€136.51 (€168.94) in the short-run and remains large in the longer run (-€172.24, SE €185.75).

Tenure We investigate treatment effect heterogeneity by tenure of the deceased worker. Columns (7) and (8) of Table 5 present treatment effects separately by tenure of the deceased worker: short (one to five years), medium (five to ten years), and long tenure (more than ten years). We find slightly smaller treatment effects associated with deaths of workers with short tenure and larger and more precisely estimated effects of deaths of workers with medium or long tenure. However, the point estimates are not estimated precisely enough to reject equality of the coefficients.

[11]Specifically, we define occupations that requires "complex specialist activities" (requirement level 3) or "highly complex activities" (requirement level 4) based on the 2010 Classification of Occupations as managerial occupations.

Occupational Specialization: Returns to Experience In a next step, we assess treatment effect heterogeneity based on a measure of specialization at the occupation level. To proxy for specialization, we rely on a measure used in Bleakley and Lin (2012) who classify occupations as relying on more specific skills when the returns to experience are high. Using a different sample of IEB records, we calculate returns to experience based on Mincer equations estimated separately for each 5-digit occupation. We then use the estimated occupation-specific returns to experience to classify occupations as having low (below 20th percentile), medium (between 20th and 80th percentile), or high (above 80th percentile) degrees of specialization.

Columns (9) and (10) of Table 5 report treatment effects on incumbent worker wages by occupational specialization of the deceased worker. The baseline effects of specialization appear to be non-monotonic in specialization. However, as in the case of heterogeneity by skills, the average effects mask heterogeneity in the effect on coworkers in the same occupation versus coworkers in other occupations. In columns (3) and (4), we document that short-run treatment effects on incumbent worker wages in the same occupation as the deceased rise in magnitude with the specialization of the deceased worker's occupation and that deaths of workers in highly specialized occupations lead to negative effects on the wages of incumbents in other occupations. For deaths of workers in occupations with high degrees of specialization, we find a short-run effect of €321.97 (SE €131.68) on coworkers in the same occupation and of -€363.93 (SE €138.04) on coworkers in other occupations.

4.5 Heterogeneity By Labor Market Thickness

Going back to Marshall (1890), economists have hypothesized that firms benefit from clustering near other firms which employ workers with similar skills so that labor market thickness could act as a force of agglomeration. For example, Moretti (2011) describes a potential benefit of labor market thickness for firms noting that "thick labor markets reduce the probability that a firm can't fill a vacancy, following an idiosyncratic shock to the labor supply of an employee" and points out that "this argument applies particularly to workers with specialized skills" (see also Lazear, 2009, for a similar argument).

Motivated by these considerations, we explore heterogeneity in the effect of worker deaths by measures of labor market thickness and occupational specialization. To proxy for labor market thickness, we measure the relative agglomeration of workers in the deceased's occupation in the local labor market. To delineate local labor markets, we focus on 50 commuting zones, following Kropp and Schwengler (2011). We measure thickness at the 5-digit occupation $\times$ commuting zone level as the share of employment in the relevant occupation in that commuting zone relative to the nationwide share of employment in that occupation.[12] We then classify 5-digit occupation × commuting zone cells as a thin or thick labor market based on a median split. As an intuitive example, the labor market for mechanical engineers in Munich will be described as thick based on this measure if Munich has a high share of mechanical engineers relative to the overall share of mechanical engineers in the German labor market.

We find that incumbent wages respond less to a worker death and the differential is particularly pronounced for specialized occupations. We report results on coworkers in the same occupation as the deceased in Table 6 (and for all coworkers in Appendix Table A-4.6) and visualize results in Figure 4d. As Figure 4d illustrates, tor the sample of all worker deaths, the point estimate for the wage effect is larger in thin labor markets compared to thick ones; however, the difference is not statistically significant. If the difference in estimates is indeed mediated through an effect of labor market thickness on firms' ease of finding suitable workers in the external labor market, one would expect this difference to be more pronounced for workers with specialized skills (Moretti, 2011). To test this prediction, we focus on a sample of deaths of workers in occupations with an above-median return to occupational experience following Section 4.4). The analysis reveals substantially larger differences between thin and thick labor markets with point estimates for the short-run wage effect of €439.78 in thin and €111.25 in thick labor markets, respectively; the difference in the effect between thick and thin labor markets is statistically significant ($p = 0.02$).

We find similar patterns when using different measures of labor market thickness to estimate heterogeneity in the treatment in panels (B) and (C) of Table 6. Two additional measures of thickness that we consider are employment density and the 3-digit industry agglomeration at the commuting zone level (defined analogously to the occupation-based agglomeration measure). For both of these measures, we find larger estimates of wage effects on incumbents in the same occupation in thin compared to thick labor markets, consistent with the hypothesis that labor market thickness mediates the response to worker exits.

We also study heterogeneity by local unemployment, as tightness (as opposed to thickness) is a key driver of matching in search-and-matching models. However, as panel (D) of Table 6, illustrates, wage effects are, if anything, larger when unemployment is high. Taken at face value, these results would be inconsistent with the predictions from a standard search-and-matching model intuition whereby firms would be able to recruit more easily when unemployment is high. However, they would be consistent with models in which higher

[12] Formally, we calculate labor market thickness for 5-digit occupation o in labor market (commuting zone) l in year d as $T_{old} = \frac{\sum_{o' \in \mathcal{O}} \frac{e_{old}}{e_{o'ld}}}{\sum_{o' \in \mathcal{O}} \frac{e_o}{e_{o'}}}$, where e_{old} denotes employment in occupation o in labor market l in year d and e_o denotes total employment in occupation o averaged over the sample period.

unemployment raises the costs for firms to find a good match, as they need to select from a larger and less selective applicant pool (Hall, 2005; Engbom, 2021; Hall and Kudlyak, 2022).

To shed further light on the relevance of labor market thickness, we assess differences in the treatment effect on hiring across labor markets (Appendix Table A-4.7 and Appendix Table A-4.8). There, we find some suggestive evidence that firms hire more externally in thick markets. For example, a death of a worker in a specialized occupation leads to 0.36 (SE 0.06) additional hires in thin markets and to 0.48 (SE 0.05) in thick markets. We find similar differences (0.35 vs. 0.50 additional hires) when measuring thickness at the industry level. For density or unemployment, we do not find a similar pattern with deaths in specialized occupations leading to similar replacement hiring.

4.6 Summary

Our main results show that worker deaths lead to increases in both the wages and retention rates of the remaining incumbent workers by about 0.6% and 0.4%, respectively, in the short run and the positive effects persist for several years. The average effects shroud substantial heterogeneity: positive effects are concentrated among incumbent workers in the same occupation group as the deceased. For deaths of high-skilled workers and managers, we estimate *negative* effects on the wages of workers in other occupation groups. Wage responses are larger when the external labor market in the deceased's occupation is thin.

5 Estimation of Implied Replacement Costs

Our reduced-form results show that firms face frictions in replacing workers externally as idiosyncratic shocks to the firm's labor supply affect the firm's labor demand for the remaining workers. A key question that arises from the reduced-form evidence is how large the frictions are that firms face in replacing workers.

To provide an empirical answer to the question, we draw on a simple model with replacement costs (Kline et al., 2019). We then estimate the model parameters with the method of simulated moments, allowing us to gauge the implied replacement costs of workers relative to the benchmark cases of no frictions and perfect substitution across workers within the firm.

5.1 Model Sketch

Static case. Our static model follows Kline et al. (2019) and we report additional derivations in Appendix A-1. Each firm $j \in \{1, ..., J\}$ starts with I_j incumbents. To reduce notation, we will omit j subscripts but note that choices and prices are firm-specific.

The firm chooses a wage w^I for incumbent workers. Incumbent workers then choose between staying at the firm or accepting an outside offer whose wage equivalent value is drawn from a distribution with CDF:

$$G(\omega) = \left(\frac{\omega - w^m}{\overline{w} - w^m}\right)^{\eta}, \qquad \omega \in [w^m, \overline{w}]. \tag{3}$$

The firm therefore expects to retain $G(w^I)I$ workers. The parameter η captures the elasticity of worker retention to the incumbent wage premium $w^I - w^m$, relative to the market wage w^m.

After the uncertainty in retention is resolved, the firm can hire new workers in the outside labor market at market wage $w^m = w^m(A)$, where A represents the amenities provided by the firm. In addition to wage costs, hiring N new workers incurs an additional recruitment cost of $c(N, I)$, which exhibits constant returns to scale so that $c(N, I) = c(N/I)I$.

The total labor employed by the firm is:

$$L = G(w^I)I + N, \tag{4}$$

and total labor costs are:

$$c\left(\frac{N}{I}\right) I + w^m N + w^I G(w^I)I. \tag{5}$$

The firm produces one unit of output per worker at the end of the period and sells it in a monopolistically competitive product market with inverse product demand curve $P(L) = P^0 L^{-1/\epsilon}$ where $\epsilon > 1$ is the demand elasticity and P^0 is a demand shifter.

The firm's profits are given by:

$$\Pi(w^I, N, I) = P(L)L - c\left(\frac{N}{I}\right) I - w^m N - w^I G(w^I)I. \tag{6}$$

The first-order conditions characterizing the firm's optimal choice of incumbent wages w^I and new hires N are:

$$MRP = w^I + \frac{w^I - w^m}{\eta}, \tag{7}$$

$$MRP = w^m + c'\left(\frac{N}{I}\right), \tag{8}$$

where the marginal revenue product of labor is defined as $MRP \equiv \frac{dP(L)L}{dL} = \frac{\epsilon - 1}{\epsilon} P(L)$.

Equating the two first-order conditions and re-arranging yields an expression for the incumbent wage premium:

$$w^I - w^m = \frac{\eta}{1+\eta} c'\left(\frac{N}{I}\right). \tag{9}$$

The markup of incumbent wages over market wages arises from positive marginal hiring costs and equals a fraction $\frac{\eta}{1+\eta}$ of the marginal hiring cost. In turn, equation (9) also offers one way of measuring replacement costs $c'(\frac{N}{I})$ as a function of the wages paid to incumbents and new hires and the shape parameter of the outside offer distribution η.

The model further illuminates the factors guiding the incumbent wage response to changes in the number of respondents, e.g., due to a worker death, with the following comparative static:

$$\frac{dw^I}{dI} = \frac{\eta}{1+\eta}\frac{\frac{dN}{dI}-\frac{N}{I}}{I}c''\left(\frac{N}{I}\right). \tag{10}$$

In the model, the incumbent wage response thus depends on the convexity of hiring costs. We show in Appendix A-1 that $\frac{dN}{dI}-\frac{N}{I}<0$. As a consequence, incumbent wages rise in respond to a negative shock to the number of incumbents, e.g., due to a worker death, if and only if hiring costs are convex. If marginal hiring costs are constant, then all adjustment in response to a worker exit happens on the hiring margin (rather than through retention of incumbent workers).

Rearranging equation (10) also demonstrates how the empirical moments we identify in the data identify replacement costs:

$$c''\left(\frac{N}{I}\right) = \frac{1+\eta}{\eta}\frac{dw^I}{dI}\frac{I}{\frac{dN}{dI}-\frac{N}{I}}, \tag{11}$$

which depend on the incumbent wage response, $\frac{dw^I}{dI}$, the hiring rate, $\frac{N}{I}$, changes in the hiring rate, $\frac{dN}{dI}$, as well as η, which we identify from scaling the retention elasticity ($\eta = \frac{d\log G(w^I)}{d\log w^I}\frac{w^I-w^m}{w^I}$).

Extension to dynamic case. We extend the model to incorporate dynamics by assuming that new hires become incumbents in the subsequent period. Each period represents one year. Letting β denote the firm's discount factor, the firm's problem is now characterized by the Bellman equation:

$$V(I_t) = \max_{w_t^I, N_t} \Pi(w_t^I, N_t, I_t) + \beta V(I_{,t+1}) \quad \text{s.t.} \quad I_{t+1} = G(w_t^I)I_t + N_t. \tag{12}$$

The only change to the FOCs (7) and (8) is the addition of $\beta V'(I_{t+1})$ on the LHS.

5.2 Model Identification and Estimation

Identification We adopt the following functional form for hiring costs:

$$c\left(\frac{N}{I}\right) = \frac{\gamma}{1+\lambda}\left(\frac{N}{I}\right)^{1+\lambda}. \tag{13}$$

The parameter γ determines the steady-state marginal hiring cost while λ determines the degree of convexity.

Given (13), the model has eight parameters: γ, λ, η, ϵ, $\overline{w}$, P^0, β, w^m. The first six parameters are estimated, and we set the remaining two. Let θ refer to the estimated parameters. Because each period represents one year, we set $\beta = 0.96$ to target a 4% discount rate. Finally, we set w^m to the sample average earnings for new hires.

To identify θ, we target the retention, hiring, and earnings response one year after an incumbent's death. Letting k denote the year relative to an incumbent death, we assume the firm is in steady state until an incumbent dies between $k = 0$ and $k = 1$, and the firm responds to the incumbent's death in year $k = 1$. We draw on the sample means before the worker death and posit that the firm has 14.51 incumbents, retains 82.6% of its incumbents, and pays its incumbents €28176. We set the number of hires to 2.17 new workers to ensure the firm is in a steady state (and also closely matching the sample mean). Our reduced-form results indicated a 0.3 percentage point increase in retention, 0.4 additional hires, and a €173 increase in incumbent earnings in response to a worker death. Therefore, in year $k = 1$ the treated firm starts with 13.48 incumbents and should retain 82.9% of its incumbents, pay them €28349, and hire 2.57 new workers. These moments identify the model parameters because they imply a system of six equations in six unknowns given by:

$$\frac{\epsilon - 1}{\epsilon} P^0 L_0^{-1/\epsilon} + \beta V'(I_0) = w_0^I(\theta) + \frac{w_0^I - w^m}{\eta}, \tag{14}$$

$$\frac{\epsilon - 1}{\epsilon} P^0 L_0^{-1/\epsilon} + \beta V'(I_0) = w^m + \gamma \left(\frac{N_0}{I_0}\right)^{\lambda}, \tag{15}$$

$$\left(\frac{w_0^I - w^m}{\overline{w} - w^m}\right)^{\eta} = 0.826, \tag{16}$$

$$\frac{\epsilon - 1}{\epsilon} P^0 L_1^{-1/\epsilon} + \beta V'(I_1) = w_1^I + \frac{w_1^I - w^m}{\eta}, \tag{17}$$

$$\frac{\epsilon - 1}{\epsilon} P^0 L_1^{-1/\epsilon} + \beta V'(I_1) = w^m + \gamma \left(\frac{N_1}{I_1}\right)^{\lambda}, \tag{18}$$

$$\left(\frac{w_1^I - w^m}{\overline{w} - w^m}\right)^{\eta} = 0.829, \tag{19}$$

where the values of I_k, L_k, N_k, and w_k^I are given by:

	I_k	L_k	N_k	w_k^I
$k = 0$	14.48	14.38	2.168	28175
$k = 1$	13.48	14.04	2.569	28380

The subscripts indicate the year k, so the first three equations represent the steady-state moments, and the last three represent the moments one year after an incumbent death.[13] The value function is obtained by solving the Bellman equation (12) with collocation, using either regular or Chebyshev polynomials.

We estimate the model using the method of simulated moments. Then we use the estimated model to simulate the event study and calculate statistics which measure the magnitude of labor market frictions.

5.3 Results

Parameter Estimates We report results in Table 7. Column 1 reports results based on short-run effects (one year after a worker death), column 2 based on long-run results (over five years).

Several clear results emerge that are consistent across specifications and point towards substantial replacement costs. First, we find high values of γ, the parameter determining the steady-state marginal hiring costs, with values ranging from €76,000 to €98,000. Second, we find moderate convexity of hiring costs, with λ being 0.09. A result of $\lambda = 0$ would have implied that all adjustment to a worker death occurred on the hiring (rather than retention) margin. Third, we find low value for η, the elasticity of incumbent retention to the incumbent wage premium, ranging between 0.2 and 0.3. These can be transformed into retention elasticities and are consistent with the reduced-form retention elasticity of 0.62. The estimate is at the lower end but within the range of estimates for the retention elasticity surveyed in meta-analyses (Manning, 2021; Sokolova and Sorensen, 2021).

As a summary measure, we calculate the implied marginal replacement cost $c'(\frac{N}{I})$ for firms in our sample and find values ranging between €65,000 and €84,000. As a benchmark, we compare these to the wages of incumbents in our worker death sample. This calculation reveals a marginal replacement cost between 2.3 and 3 annual salaries of an incumbent. Our estimates of replacement costs are substantially higher than standard estimates in the literature based on firm surveys (see, e.g., Manning, 2011). An important distinction of our results from ones based on firm surveys is that our results draw on actual employment and

[13]In the model, we target the wage response in the year after the death compared to the year before. In the data, we observe wages at an annual frequency, so we use the year ending 6–18 months before the worker death for $k = 0$ and data from the year beginning 6 months after to 6 months before the worker death for $k = 1$ response, leaving out the intervening year where there is already partial adjustment (see Table A-4.2, and Table A-4.9 for an approach breaking it out by month of death that yields results in line with the model and the no-anticipation assumption). Also, in the data we observe the wages of all coworkers; in the model 17% of workers are inframarginal leavers who have a high outside offer and will leave the firm whether it pays w_0^I or w_1^I. We compute the implied wage changes for all coworkers in the model so that it matches what we observe in the data. This logic also implies that our results may underestimate the increases in posted wages, especially 5 years out when only 30% of workers are still at their original firm (if posted wages are not passed through to workers at subsequent firms).

wage responses of firms in response to worker exits. Our results are in line with the results in Kline et al. (2019, 2021), which point to marginal replacement costs of 1.27 times the annual earnings of an incumbent and who use a similar framework but different empirical strategy with identification stemming from wage differences between new workers and incumbents and rent sharing elasticities.

As a complement to our structural estimation, we also offer a simple back-of-the-envelope calculation to assess firms' willingness to pay to retain incumbents. We had documented that, in response to a worker death, firms pay an average of €527 to their incumbents and get 0.018 more worker-years from their retained workers (in total over a period of five years). The implied expenses for retaining a full incumbent are hence equal to $527/0.018 = 28364$ or roughly one annual salary. This does not provide an upper bound on replacement costs because convex costs would make further incumbents more costly to retain. Nor does it provide a lower bound because the average cost of adjusting through hiring could be lower; it is only the marginal costs that are equalized. However, the exercise gives a sense of magnitudes of replacement costs on the retention margin. Our structural estimation gives estimates about for overall replacement costs that are substantially larger, though we find quantitatively more similar results once we incorporate the intensive margin response (which we report on in Section 6.4).

We further gauge the plausibility of the results of our dynamic structural model by tracing the paths of hiring and incumbent wages implied by our parameter estimates and compare them to reduced-form findings in Figure 5. In Panel (a), we show that the model almost perfectly replicates the observed short-run employment response to a worker death in the first three years after a worker death. In the subsequent years, we see a slight divergence with model employment fully converging while observed employment remains slightly lower. However, the difference between the model prediction and the data is not statistically significant. Panel (b) reports results for hiring in the model and the data. The model matches the overall pattern of hiring responses very well with a sharp increase in the year after the worker death and a subsequent decline. Again, the long-run differences are not statistically distinguishable even though the point estimates for hiring in the data remain slightly elevated compared to the model. Finally, we show the wage response in panel (c). Here, we see a perfect match in the first year after the event (and had noted before that period 0 for wages is muddled due to the data reporting periods). However, we see a divergence in years two through four where the observed wage response in the data remains more elevated while wages in the model converge more quickly.

Two potential hypotheses for the divergence are (i) that it might take more than one period for new workers to become incumbents (so that the effective number of incumbents remains depressed for longer), or (ii) there could be frictions in wage setting, e.g., wage rigidity, so that a firm cannot easily take back raises it granted. Our results on heterogeneity by specialization and external labor market thickness provide some support for the first hypothesis. We also gauge the explanatory power of the second hypothesis. To that end, we split our sample into firms with less or more wage flexibility (proxied by the standard deviation of period-to-period wage changes as in Jäger et al., 2020) and report results in Appendix Table A-4.10. We find that firms with more flexible wages have, on average, lower long-term wage effects. However, once we zoom into heterogeneity within and across occupations, we also detect large (absolute) effects among firms with more flexible wage policies. We therefore conclude that specialization of skills, which takes time, has more support in the data to help explain the longer-term wage effects we observe (although we leave a more definitive test to future research).

Labor Market Heterogeneity We also estimate the model separately by thickness of the external labor markets and find that estimated replacement costs are roughly twice as large in thin labor markets compared to thick ones (see columns (3) and (4) of Table 7). This is a consequence not only of the larger wage response in thin markets, but also, somewhat surprisingly, by a smaller increase in retention in thin markets (0.24 percentage points to 0.46), despite the larger wage change. This means that the change in wages required to retain an additional workers is substantially larger in thin markets.

Labor Market Heterogeneity We estimate the model with two types of workers, considering those in the same occupation as the deceased as one type, and those in other occupations as another type. In Table 4, we had shown that the wage and especially hiring responses are concentrated on the same occupation as the deceased (workers in the same one-digit occupation as the deceased make up 63% of the average firm, but 86% of the new hires). However, there is an increase in hiring for workers in other occupations, whereas if workers were so imperfectly substitutable such that $\rho < \frac{\epsilon-1}{\epsilon}$, there would be a decrease. We report results in Appendix Table A-4.14. We estimate $\rho = 0.85$, which implies an elasticity of substitution between workers in different occupations of 6.5. We also find that hiring costs are much higher for workers in other occupations, which would rationalize firms' choice to increase those workers' wages but not engage in much hiring. This could be because these occupations are disproportionately specialized or outside of the firms' area of expertise.

As a complement to our analysis of imperfect substitution between workers in different occupations, we also conduct a simple back-of-the-envelope calculation. If workers could frictionlessly move between occupations, then hiring and retention efforts should roughly track the share of workers in the deceased's occupation. However, our results show that most retention and hiring efforts occur within the deceased's occupation. That is, we observe that 63% of workers are in the same 1-digit occupation as the deceased. On average, they receive a wage increase of €239, while the point estimate for workers in other occupations is €162. This means that $\frac{0.63*239}{0.63*239+0.37*162} = 71.5\%$ of the retention expenditures in wages go towards workers in the same occupation. Therefore, about $71.5/63 - 1 \approx 13.5\%$ more of retention costs go into the same occupation. Similarly, we also calculate the share of the total wage bill increase among incumbents that goes into the same occupation (see Appendix Table **??**) and find that about 94% of the incumbent worker wage bill increase in response to a worker death occurs in the deceased's occupation, leading us to a similar quantitative conclusion.[14]

6 Alternative Models and Interpretations of Results

The framework in Section 5 drew on a wage posting model. Here, we discuss and evaluate several alternative models of wage determination as well as alternative explanations of our results. We first discuss bargaining and internal labor market models and then discuss two alternative interpretations of our findings, compensating differentials and hours changes.

6.1 Bargaining Models

Wage posting assumes zero bargaining power for workers. Here, we sketch two alternative models where workers also hold some bargaining power. As in the model in Section 5, the effects of incumbent exits depend on replacement costs.

First, we extend the model from Section 5 by giving workers bargaining power through a union. We assume that workers and the firm bargain over incumbent wages and that, after bargaining, the firm can hire as many outsiders as it wants (a version of the right-to-manage model). Relative to the static baseline model, the key difference is that (7) will be amended as incumbents can demand higher wages. The solution to the Nash bargaining problem is then characterized by:

$$\frac{w^I - w^m}{\eta} + w^I - MRP = \frac{\phi}{1-\phi}\frac{1}{g(w^I)I}\frac{\Pi - \underline{\Pi}}{w^I - w^m} \tag{20}$$

where $\underline{\Pi}$ denote the firm's profits when using only outsiders hired from the market and ϕ denotes bargaining power of the union. We provide a more comprehensive description of this extension as well as comparative statics with respect to the number of incumbents in

[14] We also estimate that the firm hires 0.35 new workers in the same occupation and 0.05 in other occupations; with linear hiring costs those correspond to 86% of the hiring expenditures being on workers in the same occupation. Incorporating convex hiring costs, that share would be higher.

Appendix A-1.3. If there are no replacement costs, the wage response will be zero. Incumbent wages will increase in response to a worker exit for sufficiently small values of worker bargaining power ϕ.

Second, an alternative framework are multi-worker firm models with intrafirm bargaining (Stole and Zwiebel, 1996a,b; Cahuc and Wasmer, 2001; Acemoglu and Hawkins, 2014). In this class of models, worker replacement on the external labor market is costly. Firms engage in pairwise negotiations with workers, taking into account that their outside option, if negotiations with an individual worker break down, is to continue negotiating with the remaining workers. Compared to the wage posting framework we adopt in Section 5, the model shares several qualitative predictions for the relationship between replacement costs and the effects of worker exits. As we show in Appendix A-2, wages of incumbent workers rise following the exit of a coworker from a firm with decreasing returns to scale and wage effects become smaller in magnitude when firms face fewer search frictions, e.g., because more outsiders are available. In the limit, wage effects of a worker exit become zero as frictions go to zero.

6.2 Internal Labor Market Models

A separate framework that could account for our findings are internal labor market models in which hiring of new workers is largely restricted to lower-level "ports of entry," higher-level vacancies are typically filled internally, and wages track seniority and job titles (Doeringer and Piore, 1971). Such models of wages tied to seniority and job titles are consistent with the finding of positive effects on wages and retention rates insofar as worker deaths increase the remaining workers' seniority and lead to a vacancy chain of promotions.

Our model in Section 5 could accommodate an internal labor market interpretation. For example, job titles might simply be labels for wage levels and firms might promote workers whenever they change their wages (e.g., to increase retention).

A version of an internal labor markets model that would be harder to square with the model in Section 5 is one in which wages sharply track positions and firms face "slot constraints" (see, e.g., Lazear and Rosen, 1981; Bianchi et al., 2022). For example, suppose a firm has two slots for staff engineers and one slot for a senior staff engineer and little leeway to adjust wages in a given position. In that case, the firm could raise incumbent wages in response to a worker exit only if the senior staff engineer exits (and one of the more junior staff engineers gets a promotion and a wage increase). In contrast, if one of the non-senior staff engineers leaves, the firm could not increase wages for the remaining engineers due to the slot constraints preventing a second senior staff engineer and having little leeway to raise wages without job title changes.

We test two key implications of this view. First, we analyze effect heterogeneity by the relative salary ranking of the deceased and the remaining incumbent workers (Column 1 and 2 of Panel A in Appendix Table A-4.11). We calculate separate treatment effects for the remaining coworkers who earned more and those who earned less than the deceased worker. In the short run, we find slightly larger effects where the deceased ranked higher than the incumbent worker (€212, SE 53) compared to cases where the deceased ranked lower (€135, SE 67). In the long run, we find effects of €115 (SE 55) where the deceased ranked higher than the incumbent worker and of €254 (SE 74) where the deceased worker ranked lower than the incumbent. We find a similar pattern of results when zooming into workers in the same occupation group as the deceased (Columns 1 and 2 of Panel B in Appendix Table A-4.11). As a complement, we also study deaths of workers by whether they are among the top 25% of a firm's salary ranking (Columns 3 and 4 of Appendix Table A-4.11). We find larger effects for deaths of workers *outside* the top salary group. Overall, the pattern of results is at odds with predictions of the slot constraints view of internal labor markets driving our main results.

Second, we also test to what extent promotions can account for the wage changes we observe. As one proxy for promotions, we test whether worker deaths trigger changes into higher-paying occupations among the remaining incumbent workers and find a small but precisely estimated 0.1 ppt (SE 0.03 ppt) increase in the probability of a promotion in the short run (Column (5) of Appendix Table A-4.3).[15] This increase in promotions is driven by those incumbent workers who were in a lower-paying occupation than the deceased (Columns 5 and 6 of Appendix Table A-4.11). To gauge to what extent such promotions can account for the wage changes we observe, we estimate specifications assigning the average wage in an occupation as outcome variable. For these specifications, we find small and significant effects indicating a wage increase of 0.12% (SE 0.15%), i.e., about four times smaller than the overall wage effect we observe. As previous work has documented that the wage effects of promotions are small relative to the average differences between jobs (Baker, Gibbs, and Holmstrom, 1994b), we believe that this likely constitutes an upper bound for the share of wage increases accounted for by promotions. Our evidence therefore does not point to promotions as the main mechanism for the wage changes we observe.

Overall, we conclude that our evidence documents the importance of internal labor markets as idiosyncratic shocks to firm-specific labor supply shape wages. However, we find less support for slot constraints driving our results, as we find wage effects among workers who initially ranked above the deceased worker in the firm's salary distribution and who do not experience higher rates of promotion. We also had already documented negative effects of

[15]We have also assessed whether a specific type of promotion, to foreman (*Meister*), may drive our results but find precisely estimated zero effects. We thank one of our referees for this suggestion.

deaths of high-skilled worker and managers on the wages of workers in other occupations, which an internal labor market model with promotions would not predict. Our overall results can be explained in a model where internal labor markets matter, e.g., because costs of replacing workers lead to a role for idiosyncratic shocks to labor supply in shaping wages, but are harder to square with models of slot constraints and little leeway in wage setting conditional on a position (consistent with Baker, Gibbs, and Holmstrom, 1994a, who document that "job levels are important to compensation, but there is also substantial individual variation in pay within levels").

6.3 Compensating Differentials

We also consider whether changes in the incumbent workers' amenity value of working at the firm could explain our findings. Prima facie, the positive wage effect could be driven by increases in incumbent workers' compensating differential of working at the firm (Rosen, 1974; Thaler and Rosen, 1976): for instance, the perception of job hazards could have increased as a consequence of a death (even though we had documented that the risk of future deaths is not increased in treatment firms). Alternatively, the amenity value of working at the firm and interacting with coworkers is lower after having lost a colleague. These explanations have in common that worker deaths could be negative shocks to coworkers' firm-specific labor supply. Such labor supply-driven explanations could explain why wages increase on average in the treatment group. However, they would also predict that workers' probability of staying with the firm decreases. The data, in contrast, reject this explanation as both the probability of staying at the firm and wages go up on average in response to a worker death. Moreover, we also find that the retention rates go up only in the same occupation as the deceased (Table 4), i.e. exactly where we found positive wage effects and further casting doubt on a compensating differential explanation. We also separately assess effects on weekends and week days, as weekend deaths are arguably less directly related to work events. If anything, we find larger effects for deaths that occur on weekends (Appendix Table A-4.12). The overall results therefore imply that shifts in firms' labor demand are indeed the driving force underlying the effects that we estimate.

6.4 Hours Changes

Our analysis of wage changes draws on wage earnings of full-time incumbent workers. Unlike other social security datasets, our data feature exact days worked so that employment duration does not affect our outcome variable mechanically. However, a key open question is to what extent the effects on wage earnings we document reflect changes in the wage rate vs. changes in work hours. Here, we revisit to what extent the effects on wage earnings may reflect hours changes and, if so, how that would change the interpretation of our findings.

We have already investigated whether worker exits affect incumbent hours at the part-time/full-time margin and found precisely estimated zero effects (although the base probability of a switch to part-time is low). The IAB administrative data generally do not feature detailed data on hours beyond the full- and part-time margin (e.g., on paid overtime work). For a limited time period, 2010 to 2015, we can draw on hours data from the accident insurance (see also Gudgeon and Trenkle, forthcoming; Dustmann et al., 2022). We analyze effects for this subperiod and report results in Appendix A-3. We find no average effects on hours worked and also no effects on hours when we analyze effects separately within and across the same occupation as the deceased. For this sample, we detect no average effect but find large positive long-run wage effects in the same occupation as the deceased and large negative effects among workers in other occupations. While we find no effects on work hours for this sample, we caution that the data may imperfectly capture actual rather than regular or contractual hours and in particular overtime and the estimates of earnings effects are imprecise for this sample.

In order to assess how the interpretation of our results would change if the wage earnings response in our main analysis also partially reflects hours changes in ways we cannot measure with the data for our main sample, we extend our model to explicitly feature an intensive margin of labor supply for incumbent workers (see Appendix A-1.4 for details). We incorporate an intensive margin by assuming that workers receive disutility from working additional hours beyond their scheduled hours and that firms will compensate them for the disutility. We derive comparative statics, showing that for sufficiently convex costs of working additional hours, worker exits would raise hours but still also lead to wage rate increases among the remaining incumbents (beyond an overtime premium). We also estimate the model and target a Hicksian elasticity of labor supply following the literature (Chetty et al., 2013). We report results in Table A-4.14 and Figures A.1 through A.4. The results imply that about 70% of the earnings response one period after an incumbent death is due to wages and the remainder due to hours. The estimates also point to substantial replacement costs on the order of magnitude of one annual salary for an incumbent (134%). Thus, once we incorporate an hours margin in our model, the results are still indicative of large costs of replacing workers.

7 Conclusion

Analyzing shocks to firm-specific labor supply due to unexpected deaths of workers, we demonstrated that firms face frictions in replacing workers externally as such worker deaths affect firms' labor demand for the remaining workers. We interpreted our results quantitatively through the lens of a model with replacement frictions. We also assessed our reduced-form results through the lens of alternative frameworks, which might be operating in tandem, and found our overall conclusions to be robust (although we acknowledge the difficulty of accounting for multiple alternative explanations operating at the same time). A key take-away of our study is that the replacement costs implied by our findings are substantially larger than most estimates in the literature (see Manning, 2011, for a survey).

A key difference of our study relative to most estimates from the literature is that we leverage a revealed-preference approach to measure wage and employment responses to employee exits rather than measuring recruitment and training costs through surveys. Why does our approach imply substantially larger costs of employee turnover than measured in firm surveys? We argue that such surveys miss three crucial and related dimensions of turnover costs. First, they miss higher costs of retaining incumbent employees who become more valuable in response to coworker turnover—a novel mechanism largely overlooked in the previous literature. Second, they miss the component of firm-specific human capital acquisition that is not embedded in worker training. If "we know more than we can tell" (Polanyi, 1967; Autor, 2014), acquisition of firm-specific human capital and, in particular, its tacit components, takes time to acquire—costs only insufficiently captured by explicit training costs. Third, they miss the costs of replacing incumbent workers with high match quality, which takes time to be revealed (Jovanovic, 1979a,b). Our evidence pointed to larger replacement costs when workers skills are specialized and when the external market for them is thin, thereby supporting specific human capital or match specificity as important correlates of replacement costs. Our evidence also pointed to longer lasting wage relative to employment effects, consistent with the idea that it takes time for newly hired workers to become insiders. We leave a deeper investigation and modeling of the processes through which newly hired workers become insiders to future research.

While our empirical analysis considered the effects of worker exits due to death, it seems plausible that our findings could be used to understand the effects of separations and quits more generally, e.g., the poaching of a worker by another firm. These other settings are potentially highly important: in the case of Germany, more than half of all vacancies are posted to replace workers who quit (Mercan and Schoefer, 2020). Nonetheless, we also caution that several differences exist between worker deaths in the smaller firms we consider and other types of worker exits. For example, a worker getting poached might recruit some of their former colleagues to the new employer. In addition, poaching constitutes useful information, e.g., about relative wages and working conditions for the original firm as well as the remaining workers who may be imperfectly informed about market wages (Jäger et al., 2022). A research design with exogenous variation in non-death worker exits would shed light on such mechanisms.

Our findings point towards several fruitful directions for future work. One promising avenue for future work will be an investigation of how different types of production hierarchies (Caliendo, Monte, and Rossi-Hansberg, 2015) amplify or decrease replacement costs, and to what extent turnover of key employees triggers reorganizations of such hierarchies. Our findings also raise the question of whether and under what conditions workers workers can change their own replaceability through entrenchment (Shleifer and Vishny, 1989), and what consequences such entrenchment may entail. Finally, our paper provided evidence supporting two key assumptions of models in which the supply of skilled workers affects firms' technology adoption (Acemoglu, 1996, 1997): firms facing frictions in replacing workers and these frictions appearing greater when human capital is firm-specific. Investigating how changes in replacement costs affect the adoption of new technologies and organizational structures by firms would thus be a natural next step.

Bibliography

Acemoglu, Daron. 1996. "A Microfoundation for Social Increasing Returns in Human Capital Accumulation." *The Quarterly Journal of Economics* 111 (3):779–804.

———. 1997. "Training and Innovation in an Imperfect Labour Market." *The Review of Economic Studies* 64 (3):445–464.

Acemoglu, Daron and William B. Hawkins. 2014. "Search with Multi-Worker Firms." *Theoretical Economics* 9 (3):583–628.

Acemoglu, Daron and Jörn-Steffen Pischke. 1998. "Why Do Firms Train? Theory and Evidence." *Quarterly Journal of Economics* 113 (1):79–119.

Antoni, Manfred, Marie Laible, and Christopher-Johannes Schild. 2015. "Establishment-Firm Linkages." *FDZ mimeo* .

Autor, David. 2014. "Polanyi's Paradox and the Shape of Employment Growth." In *Proceedings of the Federal Reserve Bank of Kansas City*. Jackson Hole Economic Policy Symposium, 129–177.

Azoulay, Pierre, Jialan Wang, and Joshua Graff Zivin. 2010. "Superstar Extinction." *Quarterly Journal of Economics* 125 (2):549–589.

Baker, George, Michael Gibbs, and Bengt Holmstrom. 1994a. "The Internal Economics of the Firm: Evidence from Personnel Data." *The Quarterly Journal of Economics* 109 (4):881–919.

———. 1994b. "The Wage Policy of a Firm." *The Quarterly Journal of Economics* 109 (4):921–955.

Becker, Gary S. 1962. "Investment in Human Capital: a Theoretical Analysis." *The Journal of Political Economy* 70 (5):9–49.

———. 1964. *Human Capital: A Theoretical and Empirical Analysis, with Special Reference to Education*. Columbia University Press.

Becker, Sascha O and Hans K Hvide. 2021. "Entrepreneur Death and Startup Performance*." *Review of Finance* 26 (1):163–185.

Bennedsen, Morten, Kasper Meisner Nielsen, Francisco Perez-Gonzalez, and Daniel Wolfenzon. 2007. "Inside the Family Firm: The Role of Families in Succession Decisions and Performance." *The Quarterly Journal of Economics* 122 (2):647–691.

Bennedsen, Morten, Francisco Perez-Gonzalez, and Daniel Wolfenzon. 2020. "Do CEOs Matter? Evidence from Hospitalization Events." *The Journal of Finance* 75 (4):1877–1911.

Bertrand, Marianne, Esther Duflo, and Sendhil Mullainathan. 2004. "How Much Should We Trust Differences-in-Differences Estimates?" *The Quarterly Journal of Economics* 119 (4):249–75.

Bianchi, Nicola, Giulia Bovini, Jin Li, Matteo Paradisi, and Michael L Powell. 2022. "Career Spillovers in Internal Labor Markets." *Review of Economic Studies* .

Biewen, Martin, Bernd Fitzenberger, and Marian Rümmele. 2022. "Using Distribution Regression Difference-in-Differences to Evaluate the Effects of a Minimum Wage Introduction on the Distribution of Hourly Wages and Hours Worked." *IZA Discussion Paper No. 15534* .

Bispinck, Reinhard, Heiner Dribbusch, and Thorsten Schulten. 2010. "German Collective Bargaining in a European Perspective: Continuous Erosion or Re-stabilisation of Multi-employer Agreements?" *WSI-Diskussionspapier No. 171* .

Bleakley, Hoyt and Jeffrey Lin. 2012. "Thick-Market Effects and Churning in the Labor Market: Evidence from US Cities." *Journal of Urban Economics* 72 (2):87–103.

Boeri, Tito, Pietro Garibaldi, and Espen R Moen. 2022. "In medio stat victus: Labor Demand Effects of an Increase in the Retirement Age." *Journal of Population Economics* 35 (2):519–556.

Brändle, Tobias, Wolf Dieter Heinbach, and Michael F. Maier. 2011. "Tarifliche Öffnung in Deutschland: Ausmaß, Determinanten, Auswirkungen." *Zeitschrift für Arbeitsmarktforschung* 44 (1-2):163–172.

Bundesagentur für Arbeit. 2011. "Klassifikation der Berufe 2010–Band 1: Systematischer und Alphabetischer Teil mit Erläuterungen." .

Cahuc, Pierre, Francois Marque, and Etienne Wasmer. 2008. "A Theory of Wages and Labor Demand with Intra-Firm Bargaining and Matching Frictions." *International Economic Review* 49 (3):943–972.

Cahuc, Pierre and Etienne Wasmer. 2001. "Does Intrafirm Bargaining Matter in the Large Firm's Matching Model?" *Macroeconomic Dynamics* 5 (5):742–747.

Caliendo, Lorenzo, Ferdinando Monte, and Esteban Rossi-Hansberg. 2015. "The Anatomy of French Production Hierarchies." *The Journal of Political Economy* 123 (4):809–852.

Card, David. 2009. "Immigration and Inequality." *Richard T. Ely Lecture, American Economic Review* 99 (2):1–21.

Card, David, Ana Rute Cardoso, Joerg Heining, and Patrick Kline. 2018. "Firms and Labor Market Inequality: Evidence and Some Theory." *Journal of Labor Economics* 36 (S1):S13–S70.

Card, David, Jörg Heining, and Patrick Kline. 2013. "Workplace Heterogeneity and the Rise of West German Wage Inequality." *Quarterly Journal of Economics* 128 (3):967–1015.

Carta, Francesca, Francesco D'Amuri, and Till M von Wachter. 2021. "Aging Workforce, Pension Reform and Firm's Outcomes." *NBER Working Paper No. 28047* .

Causa, Orsetta, Michael Abendschein, Nhung Luu, Emilia Soldani, and Chiara Soriolo. 2022. "The Post-COVID-19 Rise in Labour Shortages." *OECD Economics Department Working Papers No. 1721* .

Chetty, Raj, Adam Guren, Day Manoli, and Andrea Weber. 2013. “Does Indivisible Labor Explain the Difference between Micro and Macro Elasticities? A Meta-Analysis of Extensive Margin Elasticities.” *NBER Macroeconomics Annual* 27:1–56.

Davis, Steven J. and Till von Wachter. 2011. “Recessions and the Costs of Job Loss.” *Brookings Papers on Economic Activity* 43 (2):1–72.

Doeringer, Peter and Michael Piore. 1971. *Internal Labor Markets and Manpower Analysis*. Lexington, Massachusetts: D.C. Heath and Company.

Dustmann, Christian, Bernd Fitzenberger, Uta Schönberg, and Alexandra Spitz-Oener. 2014. “From Sick Man of Europe to Economic Superstar: Germany’s Resurgent Economy.” *The Journal of Economic Perspectives* 28 (1):167–188.

Dustmann, Christian, Attila Lindner, Uta Schönberg, Matthias Umkehrer, and Philipp Vom Berge. 2022. “Reallocation Effects of the Minimum Wage.” *The Quarterly Journal of Economics* 137 (1):267–328.

Dustmann, Christian, Johannes Ludsteck, and Uta Schönberg. 2009. “Revisiting the German Wage Structure.” *The Quarterly Journal of Economics* 124 (2):843–881.

Ellguth, Peter and Susanne Kohaut. 2020. “Tarifbindung und betriebliche Interessenvertretung: Aktuelle Ergebnisse aus dem IAB-Betriebspanel 2019.” *WSI-Mitteilungen* 73 (4):278–285.

Engbom, Niklas. 2021. “Contagious Unemployment.” *NBER Working Paper No. 28829* .

Fadlon, Itzik and Torben Heien Nielsen. 2019. “Household Labor Supply and The Gains from Social Insurance.” *Journal of Public Economics* 171:18–28.

Garin, Andrew, Filipe Silverio et al. 2018. “How Does Firm Performance Affect Wages? Evidence from Idiosyncratic Export Shocks.” *University of Illinois at Urbana-Champaign Working Paper* .

Gudgeon, Matthew and Simon Trenkle. forthcoming. “The Speed of Earnings Responses to Taxation and the Role of Firm Labor Demand.” *Journal of Labor Economics* .

Hall, Robert E. 2005. “The Amplification of Unemployment Fluctuations through Self-Selection.” *NBER Working Paper No. 11186* .

Hall, Robert E. 2011. “Recessions and the Costs of Job Loss: Comment.” *Brookings Papers on Economic Activity* 43 (2):56–61.

Hall, Robert E and Marianna Kudlyak. 2022. “Why Has the US Economy Recovered So Consistently From Every Recession in the Past 70 Years?” *NBER Macroeconomics Annual* 36 (1):1–55.

Hamermesh, Daniel S. 1996. *Labor Demand*. Princeton University Press.

Hassel, Anke. 1999. “The Erosion of the German System of Industrial Relations.” *British Journal of Industrial Relations* 37 (3):483–505.

Hethey-Maier, Tanja and Johannes Schmieder. 2013. “Does the Use of Worker Flows Improve the Analysis of Establishment Turnover? Evidence from German Administrative Data.” *Schmollers Jahrbuch - Journal of Applied Social Science Studies* 133 (4):477–510.

Imbens, Guido W. and Donald B. Rubin. 2015. *Causal Inference for Statistics, Social, and Biomedical Sciences*. Cambridge University Press.

Isen, Adam. 2013. “Dying to Know: Are Workers Paid Their Marginal Product?” *University of Pennsylvania Working Paper* .

Jacobson, Louis S., Robert J. LaLonde, and Daniel G. Sullivan. 1993. “Earnings Losses of Displaced Workers.” *The American Economic Review* 83 (4):685–709.

Jäger, Simon, Shakked Noy, and Benjamin Schoefer. forthcoming. "The German Model of Industrial Relations: Balancing Flexibility and Collective Action." *Journal of Economic Perspectives* .

Jäger, Simon, Christopher Roth, Nina Roussille, and Benjamin Schoefer. 2022. "Worker Beliefs About Outside Options." *NBER Working Paper No. 29623* .

Jäger, Simon, Benjamin Schoefer, Samuel G Young, and Josef Zweimüller. 2020. "Wages and the Value of Nonemployment." *Quarterly Journal of Economics* 135 (4):1905–1963.

Jaravel, Xavier, Neviana Petkova, and Alex Bell. 2018. "Team-Specific Capital and Innovation." *American Economic Review* 108 (4-5):1034–73.

Jones, Benjamin F. and Benjamin A. Olken. 2005. "Do Leaders Matter? National Leadership and Growth Since World War II." *The Quarterly Journal of Economics* 120 (3):835–864.

Jovanovic, Boyan. 1979a. "Firm-Specific Capital and Turnover." *The Journal of Political Economy* 87 (6):1246–1260.

———. 1979b. "Job Matching and the Theory of Turnover." *The Journal of Political Economy* 87 (5):972–990.

Katz, Lawrence F. and Kevin M. Murphy. 1992. "Changes in Relative Wages, 1963–1987: Supply and Demand Factors." *The Quarterly Journal of Economics* 107 (1):35.

Kivimäki, Mika, Marianna Virtanen, Marko Elovainio, Anne Kouvonen, Ari Väänänen, and Jussi Vahtera. 2006. "Work Stress in the Etiology of Coronary Heart Disease: a Meta-Analysis." *Scandinavian Journal of Work, Environment and Health* 32 (6):431–442.

Kline, Patrick, Neviana Petkova, Heidi Williams, and Owen Zidar. 2019. "Who Profits from Patents? Rent-Sharing at Innovative Firms." *The Quarterly Journal of Economics* 134 (3):1343–1404.

———. 2021. "Corrigendum to 'Who Profits from Patents?'." *Working Paper* .

Kropp, Per and Barbara Schwengler. 2011. "Abgrenzung von Arbeitsmarktregionen–ein Methodenvorschlag." *Raumforschung und Raumordnung* 69 (1):45–62.

Lazear, Edward P. 2009. "Firm-Specific Human Capital: A Skill-Weights Approach." *The Journal of Political Economy* 117 (5):914–940.

Lazear, Edward P. and Sherwin Rosen. 1981. "Rank-Order Tournaments as Optimum Labor Contracts." *The Journal of Political Economy* 89 (5):841–864.

Lucas, Robert E. 1978. "On the Size Distribution of Business Firms." *The Bell Journal of Economics* 9 (2):508–523.

Manning, Alan. 2011. "Imperfect Competition in the Labor Market." *Handbook of Labor Economics* 4:973–1041.

———. 2021. "Monopsony in Labor Markets: A Review." *ILR Review* 74 (1):3–26.

Marshall, Alfred. 1890. *The Principles of Economics.* New York: Macmillan.

Mercan, Yusuf and Benjamin Schoefer. 2020. "Jobs and Matches: Quits, Replacement Hiring, and Vacancy Chains." *American Economic Review: Insights* 2 (1):101–24.

Mercan, Yusuf, Benjamin Schoefer, and Petr Sedláček. forthcoming. "A Congestion Theory of Unemployment Fluctuations." *American Economic Journal: Macroeconomics* .

Moretti, Enrico. 2011. "Local Labor Markets." *Handbook of Labor Economics* 4:1237–1313.

Oettl, Alexander. 2012. "Reconceptualizing Stars: Scientist Helpfulness and Peer Performance." *Management Science* 58 (6):1122–1140.

Oi, Walter Y. 1962. "Labor As a Quasi-Fixed Factor." *The Journal of Political Economy* 70:538–555.

Paulus, Wiebke and Britta Matthes. 2013. "The German Classification of Occupations 2010: Structure, Coding and Conversion Table." *FDZ-Methodenreport* 8:2013.

Polanyi, Michael. 1967. *The Tacit Dimension.* Anchor Books ed.

Rosen, Sherwin. 1974. "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition." *The Journal of Political Economy* 82 (1):34–55.

———. 1982. "Authority, Control, and the Distribution of Earnings." *The Bell Journal of Economics* 13 (2):311–323.

Rosenbaum, Paul R. and Donald B. Rubin. 1985. "Constructing a Control Group Using Multivariate Matched Sampling Methods That Incorporate the Propensity Score." *The American Statistician* 39 (1):33–38.

Sauer, Stefan and Timo Wollmershäuser. 2021. "Shortage of Skilled Workers Is Increasingly Becoming a Burden on the German Economy." *ifo Schnelldienst digital* 2 (17):1–4.

Shleifer, Andrei and Robert W Vishny. 1989. "Management Entrenchment: The Case of Manager-Specific Investments." *Journal of Financial Economics* 25 (1):123–139.

Silva, José Ignacio and Manuel Toledo. 2009. "Labor Turnover Costs and the Cyclical Behavior of Vacancies and Unemployment." *Macroeconomic Dynamics* 13 (S1):76–96.

Slichter, Sumner H. 1919. *The Turnover of Factory Labor.* D. Appleton.

Sokolova, Anna and Todd Sorensen. 2021. "Monopsony in Labor Markets: A Meta-Analysis." *ILR Review* 74 (1):27–55.

Stole, Lars A. and Jeffrey Zwiebel. 1996a. "Intra-firm Bargaining under Non-binding Contracts." *The Review of Economic Studies* 63 (3):375–410.

———. 1996b. "Organizational Design and Technology Choice under Intrafirm Bargaining." *The American Economic Review* 86 (1):195–222.

Thaler, Richard and Sherwin Rosen. 1976. "The Value of Saving a Life: Evidence from the Labor Market." In *Household Production and Consumption*, edited by Nester Terleckyj. National Bureau of Economic Research, 265–302.

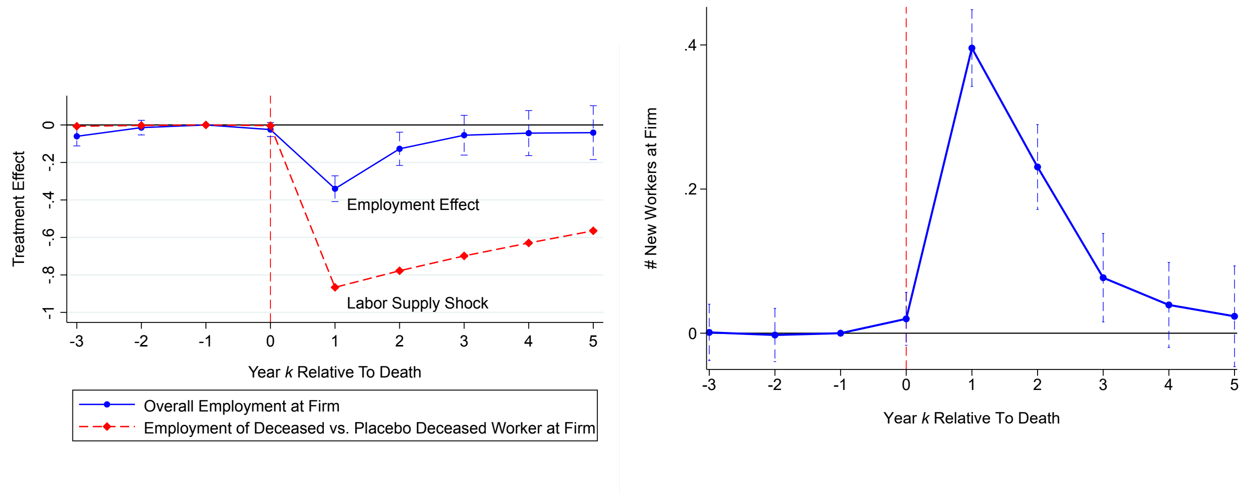
Waldinger, Fabian. 2012. "Peer Effects in Science: Evidence from the Dismissal of Scientists in Nazi Germany." *The Review of Economic Studies* 79 (2):838–861.

Figures

Figure 1: Effect of Worker Death on Employment and Hiring

(a) Labor Supply Shocks Due to Worker Deaths and Employment Effects

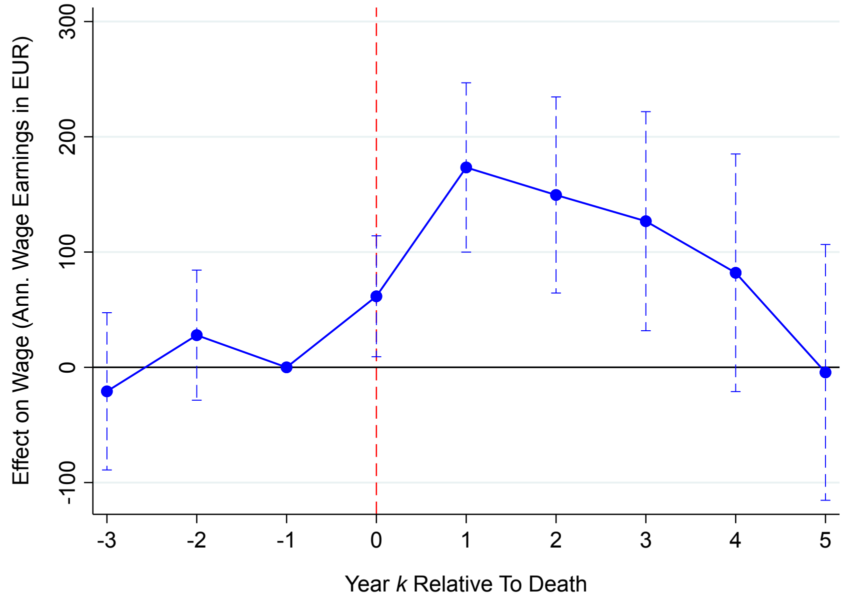
(b) Effects of Worker Deaths on Hiring



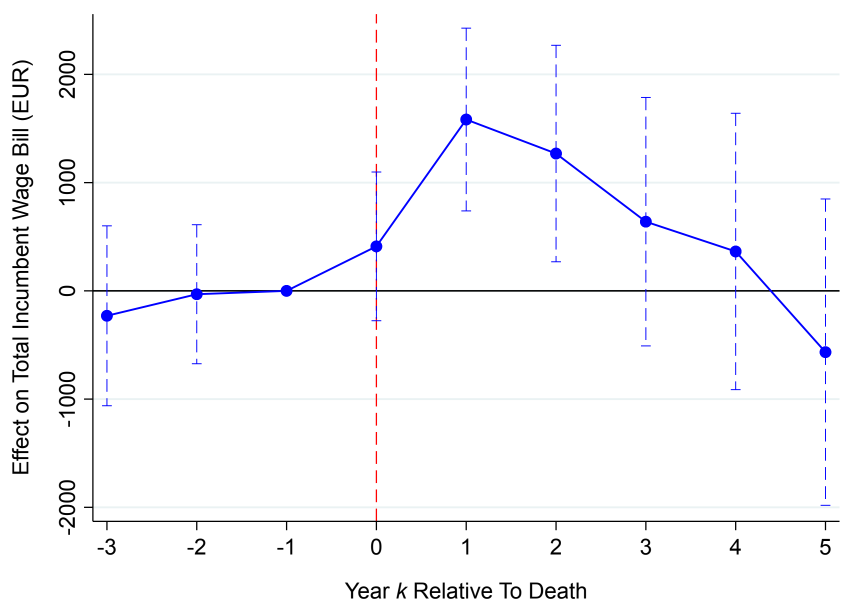
Note: The figures show regression coefficients and associated confidence intervals for the difference between treatment and comparison group in a given year k relative to the death of a worker in the treatment group firms, i.e., the $\beta_k^{Treated}$ from the difference-in-differences model in (1). The coefficient in $k = -1$ is normalized to zero. The first outcome variable in Panel (a) measures the overall employment at a firm. The comparison group mean for employment in $k = -1$ is 14.5. The labor supply shock is captured by an indicator variable that is equal to 1 if the deceased or placebo deceased is employed at the firm under study. The outcome variable in Panel (b) is the number of new workers at the firm. The comparison group mean of the number of new workers in $k = -1$ is 2.2. The dashed vertical lines denote 95% confidence intervals based on standard errors are clustered at the firm level.

Figure 2: Effect of Worker Deaths on Incumbent Worker Wages

(a) Incumbent Worker Wage Earnings

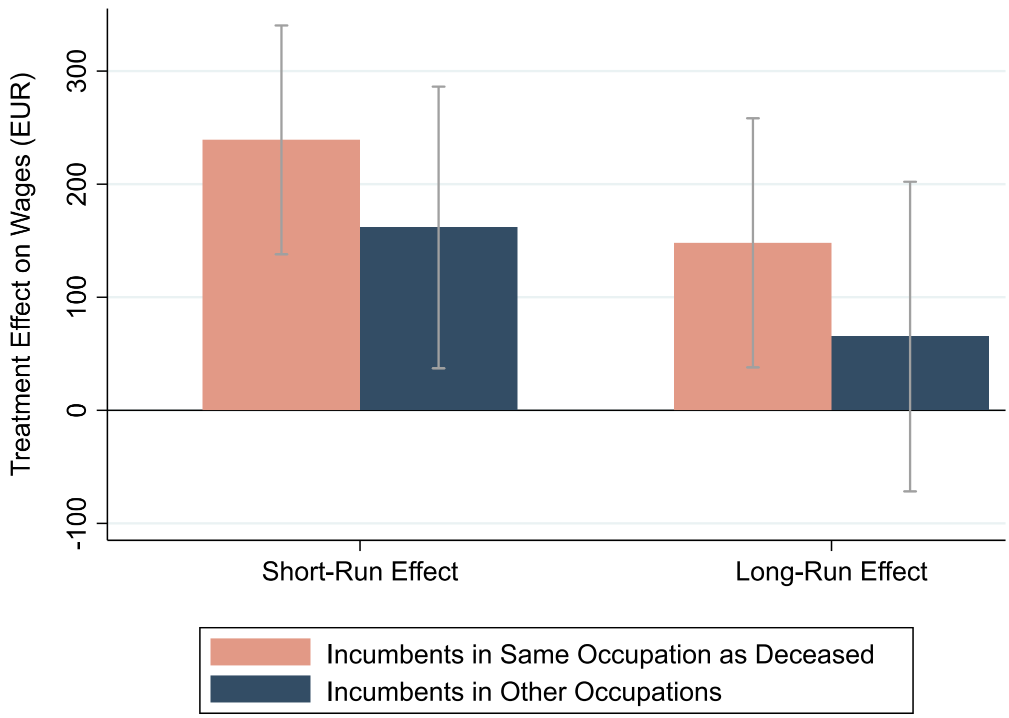


(b) Sum of Incumbent Wages in a Given Year



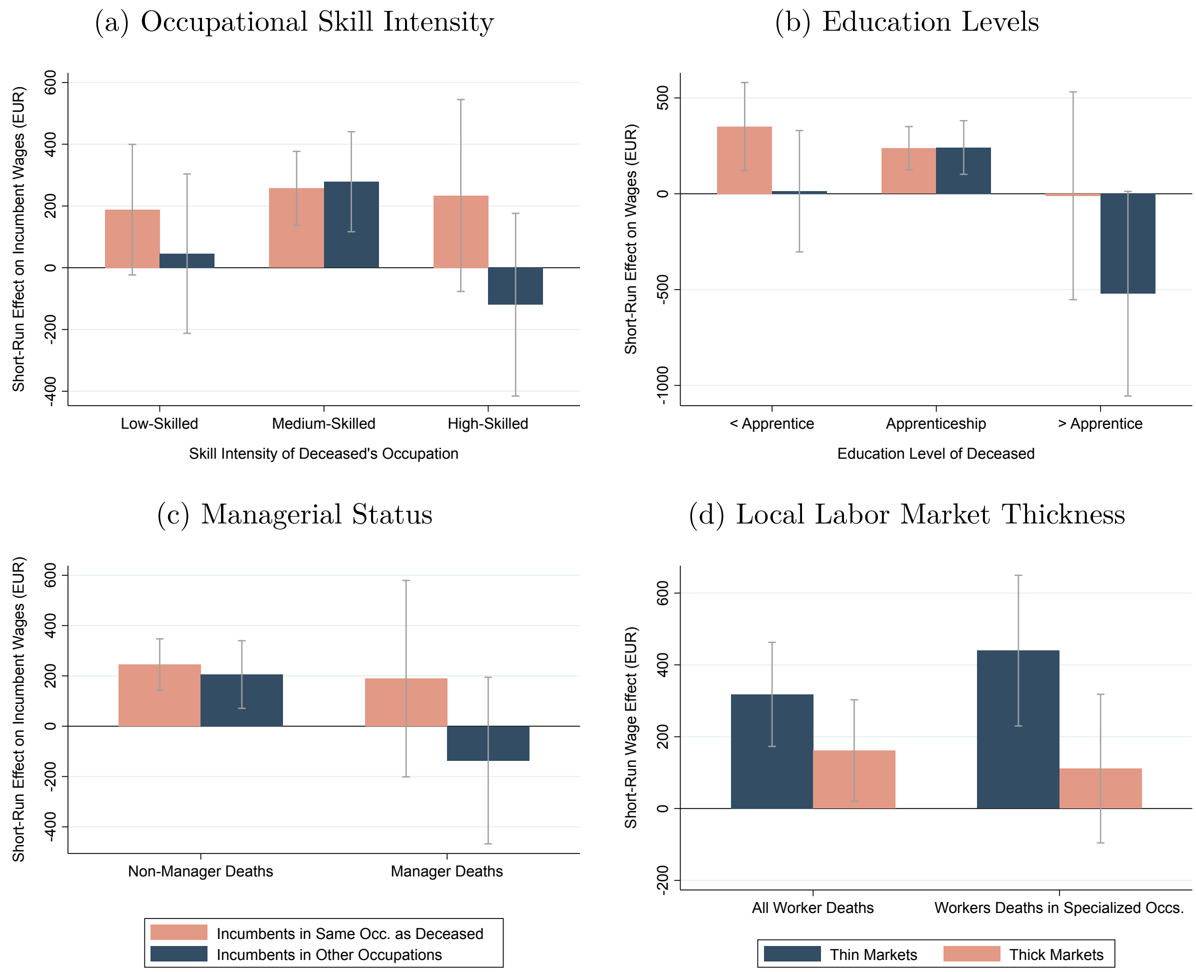
Note: The two panels display regression coefficients and associated 95% confidence intervals for the difference between incumbent worker in the treatment and comparison group, i.e., the $\beta_k^{Treated}$ from equation (2). The coefficients in $k = -1$ are normalized to zero. In the first panel, the outcome variable is the wage of an incumbent worker (scaled to correspond to yearly earnings, CPI 2010). Incumbent workers are defined as full-time coworkers of the deceased or placebo deceased in the year before death. The comparison group mean of incumbent worker wages in year k $= -1$ is €27,839 so that the €173.40 increase in $k = 1$ corresponds to a 0.6% average wage increase. In the second panel, the outcome variable is the total earnings of the set of incumbent workers, i.e., the sum of the outcome variable in the first panel over all incumbent workers in a given year relative to death k. The dashed vertical lines denote 95% confidence intervals based on standard errors clustered at the firm level. See Appendix Table A-4.2 for additional information.

Figure 3: Incumbent Wage Effects in Same vs. Other Occupations



Note: The figure displays treatment effects of worker exits on the wages of incumbents in the same 1-digit occupation group as the deceased and on incumbents in other 1-digit occupation groups. 1-digit occupation groups stratify occupations horizontally based on the thematic focus of the work, e.g., production and manufacturing vs. accounting. 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 $k = 5$. The vertical lines indicate 95% confidence intervals based on standard errors clustered at the firm level. See Table 5 for additional information.

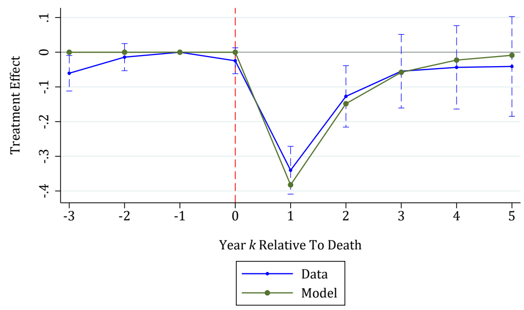
Figure 4: Heterogeneity in Incumbent Wage Effects by Skill Level of Deceased and Labor Market Thickness



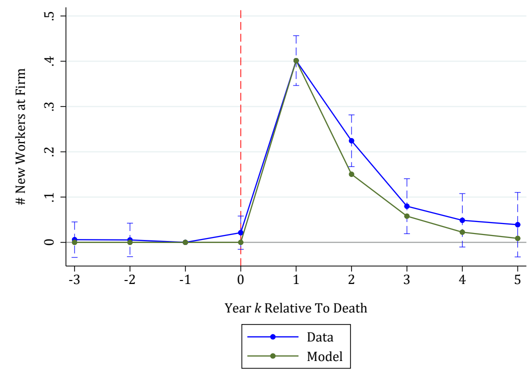
Note: The figures display short-run treatment effects of worker exits on the wages of incumbents in the same 1-digit occupation group as the deceased and, in panels (a) through (c), on incumbents in other 1-digit occupation groups for different measures of the skill level of the deceased worker. 1-digit occupation groups stratify occupations horizontally based on the thematic focus of the work, e.g., production and manufacturing vs. accounting. In panel (a), we show heterogeneity by the skill intensity of the 5-digit occupation of the deceased 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. In panel (b), we show heterogeneity by the education level of the deceased and classify workers into three groups depending on whether they have no apprenticeship training, an apprenticeship training, or further formal education. In panel (c), we show heterogeneity by 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. In panel (d), we show heterogeneity by local labor market characteristics. The first two bars plot effect heterogeneity for all worker deaths; the second two bars restrict the sample to workers in specialized occupations. Thickness is measured at the 5-digit occupation×commuting zone level as the share of employment in the relevant occupation in that commuting zone relative to the nationwide share of employment in that occupation. 5-digit occupation×commuting zone cells are characterized as thick or thin based on a median split. Occupations are classified as specialized if they have an above-median return to occupational experience (see Table 5 for more details). In all panels, the vertical lines indicate 95% confidence intervals based on standard errors clustered at the firm level. See Tables 5 and 6 and Section for additional information.

Figure 5: Model Prediction vs. Reduced-Form Effects

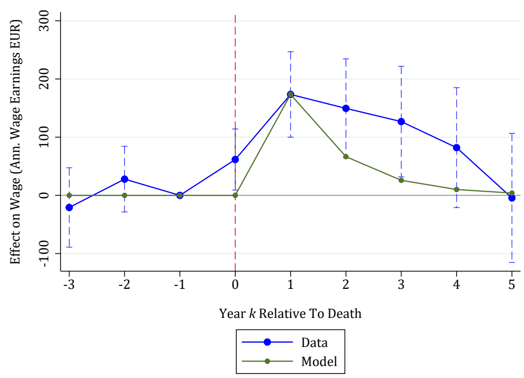
(a) Employment



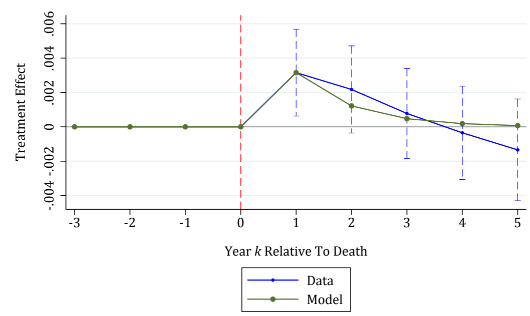
(b) Hiring



(c) Incumbent Wages



(d) Retention Rates



Note: The figure displays effects of worker deaths on several firm and incumbent worker outcomes. The blue lines report the measured effect in the data. The gray and green lines report predictions based on an estimation of the modified Kline et al. (2019) model using the method of simulated moments. See Section 5 for more details.

Tables

Table 1: Individual-Level Summary Statistics

	Actual and Placebo Deceased Workers		Incumbent Workers	
	Treatment Group	Comparison Group	Treatment Group	Comparison Group
Age	47.22	47.22	39.42	39.33
	(9.91)	(9.91)	(11.30)	(11.30)
Female	0.14	0.14	0.26	0.26
	(0.35)	(0.35)	(0.44)	(0.44)
Earnings (€, 2010 CPI)	26,098.68	26,412.74	27,770.17	27,839.64
	(9,264.10)	(9,130.92)	(13,656.44)	(13,617.7)
Years of Education	10.62	10.63	10.91	10.90
	(1.52)	(1.56)	(1.86)	(1.84)
Tenure	9.51	9.55	7.03	7.06
	(6.14)	(6.12)	(5.47)	(5.48)
N	33,786	33,786	379,728	379,728

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. Tenure measures the years of employment at the establishment.

Table 2: Firm-Level Summary Statistics

	Treatment Group	Comparison Group
Total Number of Employees	14.45	14.51
	(7.37)	(7.39)
Number of New Workers	2.16	2.16
	(2.30)	(2.32)
Number Part-Time Workers	1.19	1.19
	(2.24)	(2.25)
Number Apprentices	0.82	0.85
	(1.49)	(1.51)
Firm Age	14.78	14.80
	(6.77)	(6.78)
Primary Sector	0.029	0.029
	(0.167)	(0.168)
Secondary Sector (Manufacturing)	0.500	0.495
	(0.500)	(0.500)
Tertiary Sector (Service)	0.472	0.477
	(0.499)	(0.499)
N	33,786	33,786

Note: Standard deviations are reported in parentheses. All variables are measured in $k = -1$, the year before the actual or placebo death. Number of new workers refers to the number of workers who were employed at the establishment in $k = -1$ but not before. Firm age refers to the number of years the establishment ID has been observed in the data. The sectors are classified based on the 1973 classification of economic activities (*Klassifikation der Wirtschaftszweige* 1973).

Table 3: Treatment Effect on Incumbent Worker Employment Outcomes

	Short-Run Effect	Long-Run Effect
	Outcome: Employed at Same Establishment	
Treated	0.0032	0.0036
	(0.0013)	(0.0014)
Comparison Group Mean in $k = 1$: 0.826		
	Outcome: Full-Time Employment	
Treated	0.0007	-0.0015
	(0.0010)	(0.0010)
Comparison Group Mean in $k = 1$: 0.895		
	Outcome: Part-Time Employment	
Treated	0.00004	0.0005
	(0.0004)	(0.0005)
Comparison Group Mean in $k = 1$: 0.012		
No. of Observations	6807673	6807673

Note: The table displays treatment effects on several employment outcomes based on difference-in-differences regressions. Treated refers to the Post × 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. Standard errors are based on 67,726 clusters at the firm level.

Table 4: Effects on Outcomes Within Deceased Worker's Occupation and in Other Occupations

Outcome:	Incumbent Worker Wages		Retention		Hiring		Employment	
	Short Run	Long Run	Short Run	Long Run	Short Run	Long Run	Short Run	Long Run
Treated × Same	239.17	148.11	0.0049	0.0017	0.35	0.13	-0.39	-0.19
	(51.64)	(56.21)	(0.0017)	(0.0008)	(0.02)	(0.02)	(0.03)	(0.03)
Treated × Other	161.69	65.22	0.0002	-0.0004	0.05	0.03	0.05	0.06
	(63.57)	(69.87)	(0.0020)	(0.0010)	(0.02)	(0.02)	(0.02)	(0.03)
No. of Observations	6807673		4928792		608148		608148	
No. of Clusters	67572		67572		67572		67572	

Note: The table shows heterogeneity of the treatment 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. 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. For hiring and employment, they refer to the numbers of workers hired and the stock of workers in the same occupation and in all other occupations within the firm. The retention rate is defined as the probability of exit for a worker who is still in the same employment spell as they were at the time of the coworker death. The sample size is smaller for retention outcomes because we restrict our analysis to retention of workers who are employed at the firm at the time of the death.

Table 5: Heterogeneity of Wage Effects By Deceased's Skill Levels and Specialization

	Outcome: Incumbent Worker Wages									
Dimension of Heterogeneity:	Education		Skill		Managerial Status		Tenure		Specialization	
(Deceased Characteristic)	Short Run	Long Run	Short Run	Long Run	Short Run	Long Run	Short Run	Long Run	Short Run	Long Run
Treated × Low	195.48	94.31	120.54	56.38	205.51	133.25	117.21	36.82	119.24	115.33
	(91.50)	(101.41)	(77.69)	(85.81)	(39.19)	(43.29)	(104.60)	(113.23)	(86.93)	(96.32)
Treated × Medium	186.60	118.97	236.62	152.00			194.65	86.35	197.43	96.62
	(41.88)	(46.29)	(46.73)	(51.52)			(60.99)	(66.72)	(46.78)	(51.82)
Treated × High	-52.73	-45.49	7.52	-2.69	-59.19	-93.57	137.52	114.58	144.25	122.60
	(181.46)	(199.55)	(100.36)	(111.85)	(120.75)	(133.95)	(56.82)	(64.06)	(89.63)	(97.88)
Treated × Low × Same Occupation	350.84	310.80	188.17	126.58	244.96	136.02	134.61	174.33	221.32	223.30
	(117.18)	(129.25)	(107.91)	(114.61)	(52.14)	(56.36)	(146.08)	(154.76)	(129.85)	(143.63)
Treated × Low × Other Occupations	13.27	-194.94	45.74	-36.94	205.46	100.02	-12.80	-164.95	282.30	125.53
	(161.61)	(175.87)	(131.64)	(141.84)	(68.58)	(75.38)	(182.26)	(197.84)	(136.59)	(150.51)
Treated × Medium × Same Occupation	237.26	136.65	257.11	129.94			197.71	45.91	223.63	107.10
	(57.73)	(62.73)	(61.07)	(66.42)			(83.25)	(90.60)	(61.51)	(67.20)
Treated × Medium × Other Occupations	241.32	140.77	278.66	133.70			141.08	18.24	271.73	155.54
	(71.45)	(78.64)	(82.60)	(91.12)			(102.78)	(112.03)	(83.57)	(92.09)
Treated × High × Same Occupation	-10.47	-108.78	233.94	246.62	189.16	241.57	279.09	213.63	321.97	219.61
	(276.58)	(300.48)	(158.62)	(175.80)	(199.20)	(222.93)	(78.11)	(86.61)	(131.68)	(138.09)
Treated × High × Other Occupations	-521.38	-273.86	-119.70	-54.37	-136.51	-172.74	209.86	115.83	-363.93	-317.15
	(272.43)	(301.98)	(150.93)	(167.89)	(168.94)	(185.75)	(96.28)	(107.12)	(138.04)	(149.62)
No. of Observations	6,807,673		6,807,673		6,807,673		6,337,990		6,807,673	
No. of Coworkers	711,969		711,969		711,969		711,969		711,969	
No. of Clusters	67,572		67,572		67,572		63,233		67,572	

Note: The table shows heterogeneity of the treatment 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. 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 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). 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. In the manager column, low refers to workers we identify as non-managers and high refers to managers. We calculate a specialization measure for the occupation of the deceased worker (returns to occupation experience) and classify workers into three groups (below 20th percentile, 20th to 80th percentile, above 80th percentile). We also report heterogeneity of effects on hiring and employment in Table A-4.13. Standard errors are clustered at the firm level.

Table 6: Heterogeneity of Wage Effects and External Labor Market Characteristics

Outcome: Wages of Incumbent Workers in Same Occupation Group as Deceased						
Co-Worker Sample:	All Worker Deaths		Worker Deaths in High Specialization Occupations		Worker Deaths in Low Specialization Occupations	
	Short-Run Effect	Long-Run Effect	Short-Run Effect	Long-Run Effect	Short-Run Effect	Long-Run Effect
	(1)	(2)	(3)	(4)	(5)	(6)
(A) Thickness Measured at Occupation Level						
Treated × Low Thickness (Occupation)	317.96	199.08	439.78	225.46	221.79	183.14
	(73.93)	(80.59)	(107.06)	(113.99)	(101.75)	(112.62)
Treated × High Thickness (Occupation)	161.44	97.66	111.25	29.84	196.95	143.87
	(72.13)	(78.45)	(105.60)	(113.74)	(98.15)	(107.18)
(B) Density of Local Labor Market						
Treated × Low Density	293.33	216.64	358.69	204.80	242.38	225.94
	(71.03)	(77.88)	(102.59)	(111.12)	(97.89)	(108.12)
Treated × High Density	184.95	78.55	197.37	53.71	176.89	101.21
	(74.98)	(81.12)	(110.21)	(116.75)	(101.87)	(111.46)
(C) Thickness Measured at Industry Level						
Treated × Low Thickness (Industry)	279.25	250.78	342.06	208.83	228.33	286.74
	(74.06)	(80.52)	(105.59)	(112.88)	(103.24)	(113.45)
Treated × High Thickness (Industry)	204.16	57.17	217.05	59.28	195.46	57.13
	(71.91)	(78.09)	(106.89)	(113.80)	(96.75)	(106.11)
(D) Local Unemployment Rate						
Treated × Low Unemployment	181.64	122.69	170.01	119.64	190.66	123.99
	(82.69)	(90.56)	(121.35)	(129.71)	(112.76)	(125.42)
Treated × High Unemployment	274.17	168.69	318.71	170.83	240.19	166.13
	(78.78)	(86.45)	(112.92)	(122.38)	(108.87)	(120.25)
N	4248678		1689241		2559437	

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. The sample is restricted to incumbent workers 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 and 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.

Table 7: Estimation of Model Parameters and Implied Replacement Costs

	Short-Run Estimation	Long-Run Estimation	Thick Labor Markets (Short-Run)	Thin Labor Markets (Short-Run)
γ	76054	97944	45692	115518
λ	0.09	0.09	0.07	0.10
η	0.20	0.15	0.35	0.13
$\overline{w}$	45448	56310	35307	64726
ϵ	1.33	1.31	1.87	1.01
P^0	1147740	1394109	297754	61400900
Marginal Replacement Cost ($c'(\frac{N}{I})$)	65449	84203	40402	127148
(Expressed as % of incumbent salary)	(232%)	(299%)	(146%)	(455%)
Retention Elasticity Reduced Form	0.621		1.111	0.391

Note: The first column is estimated to match the wage, retention, and employment responses in the first year after a worker death. The second column matches the entire path of responses over a five-year horizon; see Section 5 for more information. Columns (3) and (4) split the sample by labor market thickness and report replacement costs for both specifications separately. See Section 5 for additional information.

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

Simon Jäger and Jörg Heining

Contents

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:

$$MRP + \beta V'(G(w_t^I)I_t + N_t) = w_t^I + \frac{w_t^I - w^m}{\eta}, \tag{21}$$
$$MRP + \beta V'(G(w_t^I)I_t + N_t) = w^m + c'\left(\frac{N_t}{I_t}\right). \tag{22}$$

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*

$$\begin{aligned}
\frac{dMRP}{dI} &= \frac{1+\eta}{\eta}\frac{dw^I}{dI}, \\
\frac{dMRP}{dI} &= \frac{c''\left(\frac{N}{I}\right)}{I}\left(\frac{dN}{dI} - \frac{N}{I}\right), \\
\frac{dMRP}{dI} &= -\frac{1}{\epsilon}MRP\frac{dL}{dI}\frac{1}{L}, \\
\frac{dL}{dI} &= \frac{dN}{dI} + I\eta G(w^I)\frac{1}{w^I - w^m}\frac{dw^I}{dI} + G(w^I).
\end{aligned} \tag{23}$$

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 and 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 and 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, €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

$$\max_N P^0(G(w^I)I + N)^{1-1/\epsilon} - c\left(\frac{N}{I}\right) I - w^m N - w^I G(w^I) I. \tag{24}$$

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:

$$\max_{w^I} \left(w^I - w^m\right)^{\phi} \left(\Pi(w^I, I) - \underline{\Pi}\right)^{1-\phi}, \tag{25}$$

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:

$$0 = \phi \frac{1}{w^I - w^m} + (1-\phi) \frac{\partial_{w^I} \Pi(w^I, I)}{\Pi(w^I, I) - \underline{\Pi}}. \tag{26}$$

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-1.2 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*

$$\frac{dMRP}{dI} = c''\left(\frac{N}{I}\right) I^{-1}\left(\frac{dN}{dI} - \frac{N}{I}\right) \tag{27}$$

$$\frac{dMRP}{dI} = \frac{1+\eta}{\eta}\frac{dw^I}{dI} - \frac{d\mathcal{B}}{dI} \tag{28}$$

$$\mathcal{B} \equiv \frac{\phi}{1-\phi}\frac{1}{g(w^I)I}\frac{\Pi(\cdot) - \underline{\Pi}}{w^I - w^m} \tag{29}$$

$$\frac{d\mathcal{B}}{dI} = \mathcal{B}\left(\frac{1}{\Pi(w^I, I) - \underline{\Pi}}\frac{d\Pi}{dI} - \eta\frac{1}{w^I - w^m}\frac{dw^I}{dI}\right) \tag{30}$$

$$\frac{dMRP}{dI} = -\frac{1}{\epsilon}MRP\frac{dL}{dI}\frac{1}{L} \tag{31}$$

$$\frac{dL}{dI} = \frac{dN}{dI} + Ig(w^I)\frac{dw^I}{dI} + G(w^I). \tag{32}$$

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 (30). □

Proposition A-1.2. *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 (28) 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

$$\begin{aligned} & P^0 Q^{\frac{\epsilon-1}{\epsilon}} - c\left(\frac{N}{I}\right) I - w^m N \\ & - \left(w^I \frac{h^I}{40} + \frac{\chi}{40}\frac{1}{1+\psi}((h^I)^{1+\psi} - 40^{1+\psi})\right) G(w^I) I, \end{aligned} \tag{33}$$

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-1.3. *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 (33) 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

$$r(w^I, h^I) = (1-\tau)w^I - \frac{\chi}{1+\psi}((h^I)^{1+\psi} - \phi^{1+\psi}) \tag{34}$$

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:

$$G(\omega) = \left(\frac{\frac{\omega}{1-\tau} - w^m}{\overline{w} - w^m}\right)^{\eta}. \tag{35}$$

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

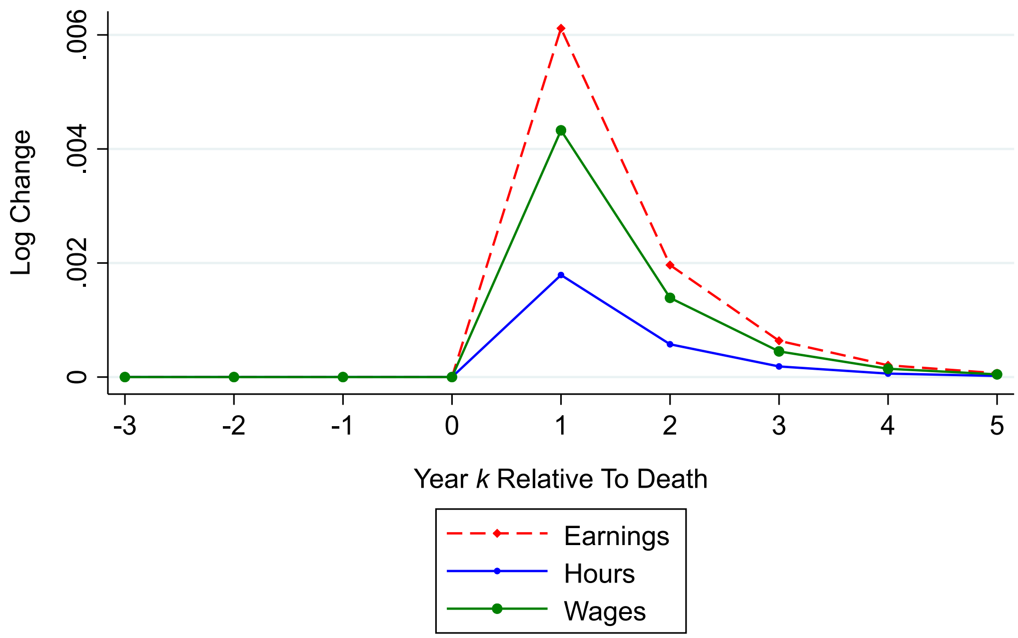


Figure A.2: Labor Supply Shock and Employment Effects Of Worker Death

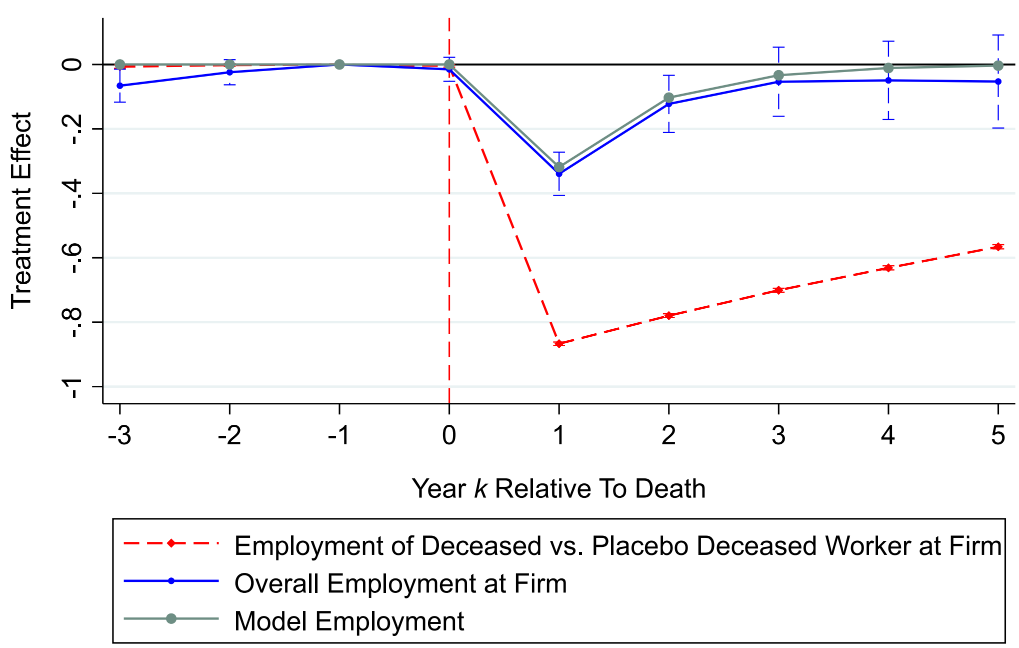


Figure A.3: Effect of Worker Death on Hiring

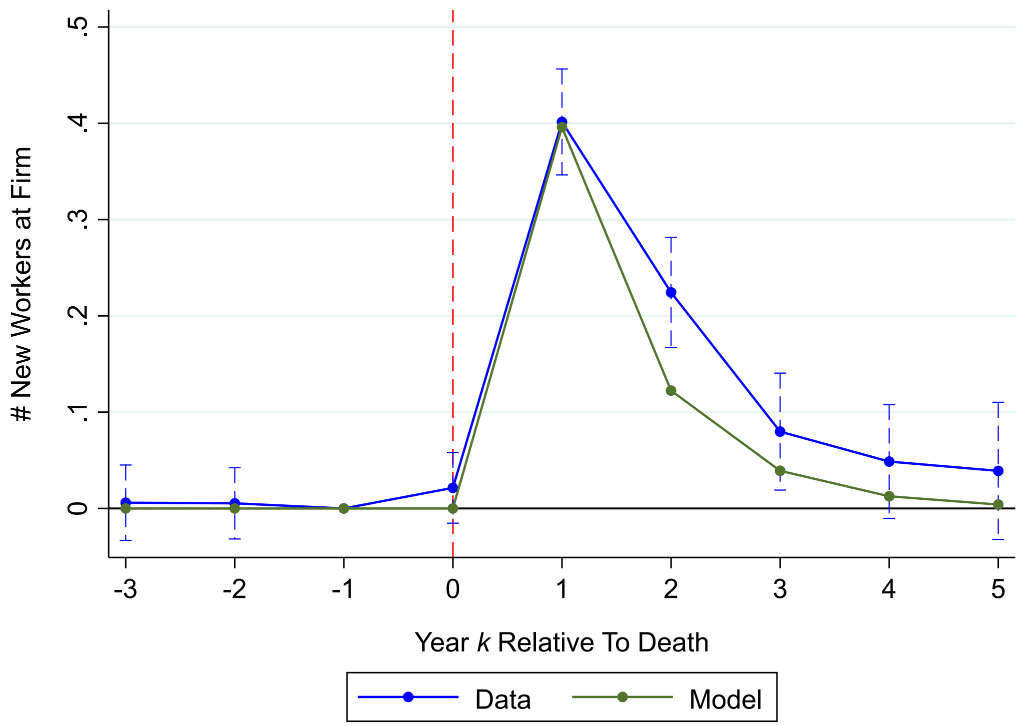
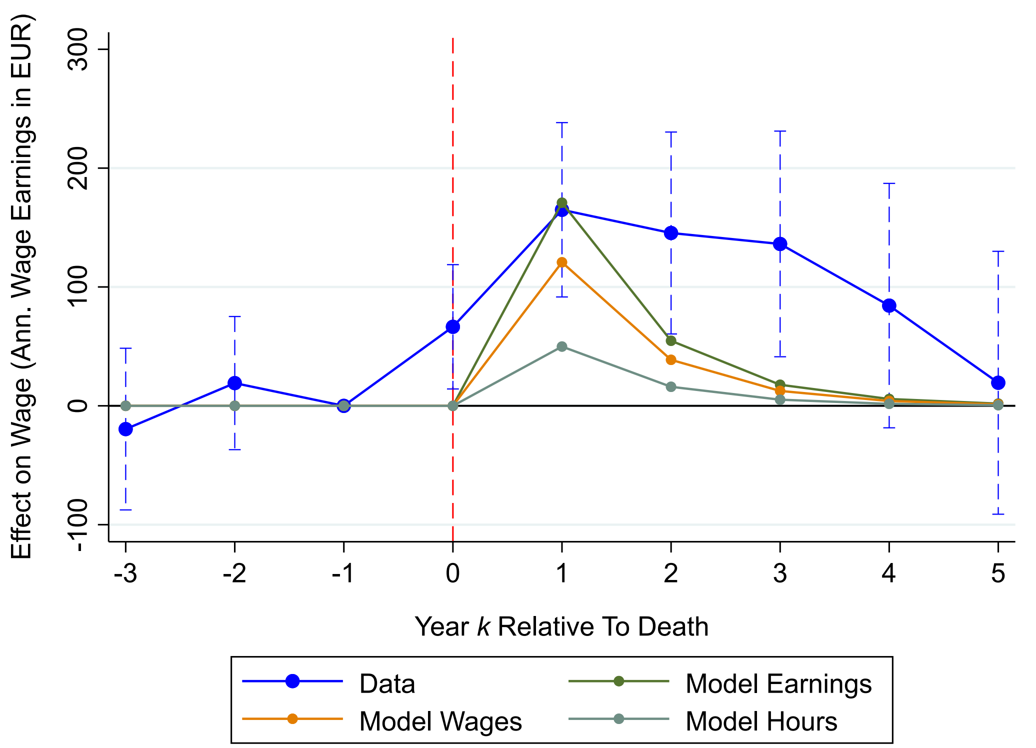


Figure A.4: Earnings, Wages and Hours Responses



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 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, $\frac{dN}{dI} < 0$.

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

$$MRP = w^m + c'\left(\frac{N}{I}\right) \tag{36}$$

$$MRP = w^I + \frac{w^I - w^m}{\eta} + \frac{\chi}{1+\psi}((h^I)^\psi - 40^{1+\psi}/h^I) \tag{37}$$

$$MRP = w^I + \chi(h^I)^\psi \tag{38}$$

$$\frac{w^I - w^m}{\eta} = \frac{\chi}{h^I}\frac{1}{1+\psi}\left(\psi(h^I)^{1+\psi} + 40^{1+\psi}\right) \tag{39}$$

$$\begin{aligned} MRP &= \frac{P(L)L}{L} \\ &= \left(\frac{\epsilon - 1}{\epsilon}\right) P^0 T^{1-1/epsilon} L^{-1/epsilon} \end{aligned} \tag{40}$$

$$P(L) = P^0 L^{-1/epsilon} \tag{41}$$

$$L = N + G(w^I)I\frac{h^I}{40}. \tag{42}$$

To obtain the comparative statics in Proposition A-1.3 implicitly differentiate these conditions to obtain the following lemma.

Lemma A-1.2. *The equilibrium response to an exogenous shock in I is characterized by the following system of equations:*

$$\frac{dMRP}{dI} = \frac{c''(\frac{N}{I})}{I}\left(\frac{dN}{dI} - \frac{N}{I}\right) \tag{43}$$

$$\frac{dMRP}{dI} = \frac{1+\eta}{\eta}\frac{dw}{dI} + \chi\frac{\psi}{1+\psi}(h^I)^{\psi-1}\frac{dh^I}{dI} + \chi\frac{1}{1+\psi}40^{1+\psi}(h^I)^{-2}\frac{dh^I}{dI} \tag{44}$$

$$\frac{dMRP}{dI} = \frac{dw^I}{dI} + \chi\psi(h^I)^{\psi-1}\frac{dh^I}{dI} \tag{45}$$

$$\frac{dMRP}{dI} = -\frac{1}{\epsilon}MRP\frac{1}{L}\frac{dL}{dI} \tag{46}$$

$$\frac{dL}{dI} = \frac{dN}{dI} + G(w^I)\frac{h^I}{40} + g(w^I)I\frac{h^I}{40}\frac{dw^I}{dI} + G(w^I)I\frac{1}{40}\frac{dh^I}{dI}. \tag{47}$$

$$\tag{48}$$

Further, the wage and hours response are related by

$$\frac{dw^I}{dI} = \frac{\eta\chi}{1+\psi}40^{1+\psi}\left(\psi^2\left(\frac{h^I}{40}\right)^{1+\psi} - 1\right)(h^I)^{-2}\frac{dh^I}{dI}. \tag{49}$$

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

Proposition A-1.4. *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-1.2 and Proposition A-1.4. We then conclude this subsection with the proof of Proposition A-1.3.

Proof of Lemma A-1.2. Implicitly differentiate the FOCs in (36) - (42) to obtain (43) - (47).

To derive (48), recognize that

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

Rearrange.

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

□

Proof of Proposition A-1.4. In every equation of (43) - (47), replace $40^{1+\psi}$ by 0. Then (48) becomes

$$
\frac{dw^I}{dI} = \frac{\eta\chi}{1+\psi}\psi^2(h^I)^{1+\psi}(h^I)^{-2}\frac{dh^I}{dI}, \tag{50}
$$

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 (47), (46), and strict convexity of $c(N/I)$. Since the sign of the wage and hours responses are the same, (45) implies $\frac{dw}{dI} > 0$ and $\frac{dh^I}{dI} > 0$. But in that case, (47) 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 (43), (44), and (48). 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 (43) 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. $\square$

Proof of Proposition A-1.3. 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

$$\frac{dw^I}{dI} = \frac{\eta\chi}{1+\psi}40^{\psi-1}(\psi^2-1)\frac{dh^I}{dI} = \eta\chi 40^{\psi-1}(\psi-1)\frac{dh^I}{dI}. \tag{51}$$

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-1.4 proves that $\frac{dMRP}{dI} < 0$, $\frac{dw^I}{dI} < 0$, and $\frac{dh^I}{dI} < 0$. From (51), 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, (43) 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 (51), 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 (39) 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. $\square$

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 and 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 and Gans, 2003); third, in a search-and-matching model with heterogeneous labor and wage bargaining following Cahuc, Marque, and Wasmer (2008) (see also Wolinsky (2000); Elsby and Michaels (2013); Acemoglu and 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.[16] 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 and 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 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

[16] 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 and Katz, 1991, and Kahn, 2013) while others are more consistent with a model in which employer learning about worker ability is public information (Farber and Gibbons 1996; Altonji and Pierret 2001 and Schönberg, 2007). Felli and Harris (1996) provide a model that shows how information about match quality with a given employer can be interpreted as firm-specific human capital.

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 $F(N) : \mathbb{N} \to \mathbb{R}_+$. 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.[17] 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.[18] Labor contracts are assumed to be non-binding in the sense that no long-term contracts can be written.[19] 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 $\underline{w}$:

$$\underbrace{\tilde{\pi}(N) - \tilde{\pi}(N-1)}_{\text{Firm's surplus}} = \underbrace{\tilde{w}(N) - \underline{w}}_{\text{Worker's surplus}} . \tag{52}$$

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:

$$\tilde{w}(1) = \underline{w} + \frac{1}{2}(\Delta F(1) - \underline{w}) = \frac{1}{2}(\Delta F(1) + \underline{w}). \tag{53}$$

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

[17]The setup can be easily extended to situations with asymmetric bargaining power as in section A-2.3.

[18]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, and 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.

[19]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 $\pi(N) = F(N) - \underline{w}N$.

worker break down the profit will be $\tilde{\pi}(1) = F(1) - \tilde{w}(1)$ so that the splitting rule requires that:

$$\Delta F(2) - \tilde{w}(2) + [\tilde{w}(1) - \tilde{w}(2)] = \tilde{w}(2) - \underline{w}. \tag{54}$$

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

$$\tilde{w}(2) = \frac{1}{3}\Delta F(2) + \frac{1}{6}\Delta F(1) + \frac{1}{2}\underline{w}. \tag{55}$$

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:[20]

$$\tilde{w}(N) = \frac{1}{N(N+1)} \sum_{i=0}^{N} i\Delta F(i) + \frac{1}{2}\underline{w}. \tag{56}$$

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 (56) can be used to calculate how the wages of the remaining $N-1$ incumbent workers change when a worker exits the firm:

$$\underbrace{\tilde{w}(N-1) - \tilde{w}(N)}_{\text{Wage Change}} = \frac{1}{N+1}\left(\sum_{i=0}^{N-1} \underbrace{\frac{2i}{N(N-1)}\Delta F(i)}_{\substack{\text{Weighted Marginal Product}\\ \text{of } i\text{th worker}}} - \underbrace{\Delta F(N)}_{\substack{\text{Marginal Product}\\ \text{of } N\text{th worker}}}\right). \tag{57}$$

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 $N-1$.[21] 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 $\Delta F(i) < \Delta F(N), \forall i < N$.

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

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

In the Cahuc, Marque, and 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 and 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 and 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 and 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 $\underline{w}$:

$$\tilde{w}_{\bar{N}-N}(N) = \left(\frac{N}{N+1}\right)^{\bar{N}-N} \tilde{w}(N) + \left(1 - \left(\frac{N}{N+1}\right)^{\bar{N}-N}\right) \underline{w}. \tag{58}$$

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 (56) 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 (58), the wage change for incumbent workers when a worker exits from the firm and outsiders are available ($\bar{N} > N$) corresponds to:

$$\tilde{w}_{\bar{N}-1-N}(N) - \tilde{w}_{\bar{N}-N}(N) = \left(\frac{N}{N+1}\right)^{\bar{N}-N} \frac{1}{N}\left(\tilde{w}(N) - \underline{w}\right). \tag{59}$$

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 (59), 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, and 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 $\mathrm{N} = (N_1, ..., N_n)$ 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 $q_i(\theta_i) = h_i(u_i, V_i)/V_i$.[22] Existing jobs are destroyed at an exogenous destruction rate of s_i. The wage of workers of type i is denoted by $w_i(\mathrm{N})$ as it can

[22]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.

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:

$$\Pi(\mathrm{N}) = \max_{\mathrm{V}} \left(\frac{1}{1 + r\,dt}\right) \left\{ \left[F(\mathrm{N}) - \sum_{j=1}^{n} (w_j(\mathrm{N})N_j - \gamma_j V_j) \right] dt + \Pi(\mathrm{N}^+) \right\}, \tag{60}$$

subject to the law of motion for employment

$$N_i^+ = N_i(1 - s_i\,dt) + V_i q_i\,dt,\ \forall i \in \{1, .., n\}. \tag{61}$$

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:

$$\underbrace{\frac{F_i(\mathrm{N}) - w_i(\mathrm{N}) - \sum_{j=1}^{n} N_j \frac{\partial w_j(\mathrm{N})}{\partial N_i}}{r + s_i}}_{\text{Marginal Benefit of Employment of Type } i} = \underbrace{\frac{\gamma_i}{q_i}}_{\text{Marginal Cost of Hiring}} . \tag{62}$$

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

$$\underbrace{F_i(\mathrm{N})}_{\text{Marginal Product}} = \underbrace{w_i(\mathrm{N})}_{\text{Wage}} + \underbrace{\frac{\gamma_i(r + s_i)}{q_i}}_{\text{Turnover Costs}} + \underbrace{\sum_{j=1}^{n} N_j \frac{\partial w_j(\mathrm{N})}{\partial N_i}}_{\text{Employment Wage Effect}}. \tag{63}$$

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 and 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:

$$\beta \underbrace{\frac{\partial \Pi(\mathrm{N})}{\partial N_i}}_{\substack{\text{Firm's} \\ \text{Marginal Profit}}} = (1 - \beta) \underbrace{\frac{w_i(N) - rU_i}{r + s_i}}_{\substack{\text{Worker's} \\ \text{Surplus}}}, \tag{64}$$

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.[23] Cahuc, Marque, and Wasmer (2008) derive the wage $w_i(\mathrm{N})$ earned by workers of type i:

$$w_i(\mathrm{N}) = (1-\beta)rU_i + \int_0^1 z^{\frac{1-\beta}{\beta}} F_i(\mathrm{N}z)\, dz. \tag{65}$$

The wage expression has an intuitive interpretation similar to the Stole and Zwiebel formula in (56). 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 (56), when $\beta = \frac{1}{2}$.

Equation (65) 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:

$$\frac{\partial w_i(\mathrm{N})}{\partial N_j} = \int_0^1 z^{\frac{1}{\beta}} F_{ij}(\mathrm{N}z)\, dz. \tag{66}$$

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

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

for worker type j. Directly following the worker exit, the wage effect of a j-worker exit on i-worker wages will be $-\frac{\partial w_i(\mathrm{N})}{\partial N_j}$ as employment of worker type j has changed by -1; in the next period, the wage effect will be $-\frac{\partial w_i(\mathrm{N})}{\partial N_j}(1-q_j(\theta_j))$, 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:

$$\sum_{t=0}^{\infty}\frac{\partial w_i(\mathrm{N})}{\partial N_j}\Delta N_{jt} = -\sum_{t=0}^{\infty}\frac{\partial w_i(\mathrm{N})}{\partial N_j}(1-q_j(\theta_j))^t = -\frac{\partial w_i(\mathrm{N})}{\partial N_j}\frac{1}{q_j(\theta_j)}. \tag{67}$$

According to (67), 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 and 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, and 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 and 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, and 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 -€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.[24]

Online Appendix References

Acemoglu, Daron and William B. Hawkins. 2014. "Search with Multi-Worker Firms." *Theoretical Economics* 9 (3):583–628.

Altonji, Joseph G. and Charles R. Pierret. 2001. "Employer Learning and Statistical Discrimination." *The Quarterly Journal of Economics* 116 (1):313–350.

Brügemann, Björn, Pieter Gautier, and Guido Menzio. 2019. "Intra Firm Bargaining and Shapley Values." *Review of Economic Studies* 86:564–592.

Cahuc, Pierre, Francois Marque, and Etienne Wasmer. 2008. "A Theory of Wages and Labor Demand with Intra-Firm Bargaining and Matching Frictions." *International Economic Review* 49 (3):943–972.

Cahuc, Pierre and Etienne Wasmer. 2001. "Does Intrafirm Bargaining Matter in the Large Firm's Matching Model?" *Macroeconomic Dynamics* 5 (5):742–747.

Chetty, Raj, Adam Guren, Day Manoli, and Andrea Weber. 2013. "Does Indivisible Labor Explain the Difference between Micro and Macro Elasticities? A Meta-Analysis of Extensive Margin Elasticities." *NBER Macroeconomics Annual* 27:1–56.

De Fontenay, Catherine C. and Joshua S. Gans. 2003. "Organizational Design and Technology Choice under Intrafirm Bargaining: Comment." *The American Economic Review* 93 (1):448–455.

Dustmann, Christian, Attila Lindner, Uta Schönberg, Matthias Umkehrer, and Philipp Vom Berge. 2022. "Reallocation Effects of the Minimum Wage." *The Quarterly Journal of Economics* 137 (1):267–328.

Elsby, Michael W. L. and Ryan Michaels. 2013. "Marginal Jobs, Heterogeneous Firms, and Unemployment Flows." *American Economic Journal: Macroeconomics* 5 (1):1–48.

Farber, Henry S. and Robert Gibbons. 1996. "Learning and Wage Dynamics." *The Quarterly Journal of Economics* 111 (4):1007–1047.

Felli, Leonardo and Christopher Harris. 1996. "Learning, Wage Dynamics, and Firm-Specific Human Capital." *The Journal of Political Economy* 104 (4):838–868.

Gibbons, Robert and Lawrence F. Katz. 1991. "Layoffs and Lemons." *Journal of Labor Economics* 9:351–380.

Greenwald, Bruce C. 1986. "Adverse Selection in the Labour Market." *The Review of Economic Studies* 53 (3):325–347.

[24]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.

Grossman, Sanford J. and Oliver D. Hart. 1986. “The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration.” *The Journal of Political Economy* 94 (4):691–719.

Gudgeon, Matthew and Simon Trenkle. forthcoming. “The Speed of Earnings Responses to Taxation and the Role of Firm Labor Demand.” *Journal of Labor Economics* .

Hawkins, William B. 2015. “Bargaining with Commitment Between Workers and Large Firms.” *Review of Economic Dynamics* 18 (2):350–364.

Kahn, Lisa. 2013. “Asymmetric Information between Employers.” *American Economic Journal: Applied Economics* 5 (4):165–205.

Kline, Patrick, Neviana Petkova, Heidi Williams, and Owen Zidar. 2019. “Who Profits from Patents? Rent-Sharing at Innovative Firms.” *The Quarterly Journal of Economics* 134 (3):1343–1404.

Lachowska, Marta, Alexandre Mas, and Stephen Woodbury. 2022. “How Reliable Are Administrative Reports of Paid Work Hours?” *Labour Economics* 75:102131.

Pissarides, Christopher A. 2000. “Equilibrium Unemployment Theory.” *MIT Press Books* .

Schönberg, Uta. 2007. “Testing for Asymmetric Employer Learning.” *Journal of Labor Economics* 25 (4):651–691.

Statistisches Bundesamt. 2016. “Verdienststrukturerhebung, 2014.” *Fachserie 16, Heft 1* .

Stole, Lars A. and Jeffrey Zwiebel. 1996a. “Intra-firm Bargaining under Non-binding Contracts.” *The Review of Economic Studies* 63 (3):375–410.

———. 1996b. “Organizational Design and Technology Choice under Intrafirm Bargaining.” *The American Economic Review* 86 (1):195–222.

Su, Che-Lin and Kenneth L. Judd. 2012. “Constrained Optimization Approaches to Estimation of Structural Models.” *Econometrica* 80 (5):2213–2230.

Waldman, Michael. 1984. “Job Assignments, Signalling, and Efficiency.” *The RAND Journal of Economics* 15 (2):255–267.

Wolinsky, Asher. 2000. “A Theory of the Firm with Non-binding Employment Contracts.” *Econometrica* 68 (4):875–910.

A-4 Additional Tables and Figures

A-4.1 Additional 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.

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.

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.

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

Outcome:	New Hire Wages
Treated × $k = -3$	112.21
	(79.80)
Treated × $k = -2$	174.54
	(79.94)
Treated × $k = -1$	omitted
Treated × $k = 0$	169.55
	(77.66)
Treated × $k = 1$	1201.31
	(79.38)
Treated × $k = 2$	727.01
	(84.48)
Treated × $k = 3$	283.66
	(87.68)
Treated × $k = 4$	74.49
	(90.65)
Treated × $k = 5$	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).

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.

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	Long-Run Effect	Short-Run Effect	Long-Run Effect	Short-Run Effect	Long-Run Effect
	(1)	(2)	(3)	(4)	(5)	(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 $1(\text{period}_k)$ with the covariate. To calculate a specialization measure for the occupation of the deceased worker, we follow Bleakley and 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.

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	Long-Run Effect	Short-Run Effect	Long-Run Effect	Short-Run Effect	Long-Run Effect
	(1)	(2)	(3)	(4)	(5)	(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 $1(\text{period}_k)$ with the covariate. To calculate a specialization measure for the occupation of the deceased worker, we follow Bleakley and 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.

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	Long-Run Effect	Short-Run Effect	Long-Run Effect	Short-Run Effect	Long-Run Effect
	(1)	(2)	(3)	(4)	(5)	(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 $1(\text{period}_k)$ 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 and 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.

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

Outcome:	Wage in Year $k = 0$
Treated × Death in July, August, September of $k = 0$	162.75
	(41.30)
Treated × Death in October, November, December of $k = 0$	56.37
	(42.62)
Treated × Death in January, February, March of $k = 1$	18.04
	(43.18)
Treated × 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.

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 baed on difference-in-differences (DiD) regressions. Treated refers to the Post × 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.

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.

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 × 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.

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 $1(\text{period}_k)$ 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 and 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.

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.

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.

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

	Short-Run Effect	Long-Run Effect	Short-Run Effect	Long-Run Effect
Outcome: Incumbent Worker Hours				
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 $1(\text{period}_k)$ 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.

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.

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.

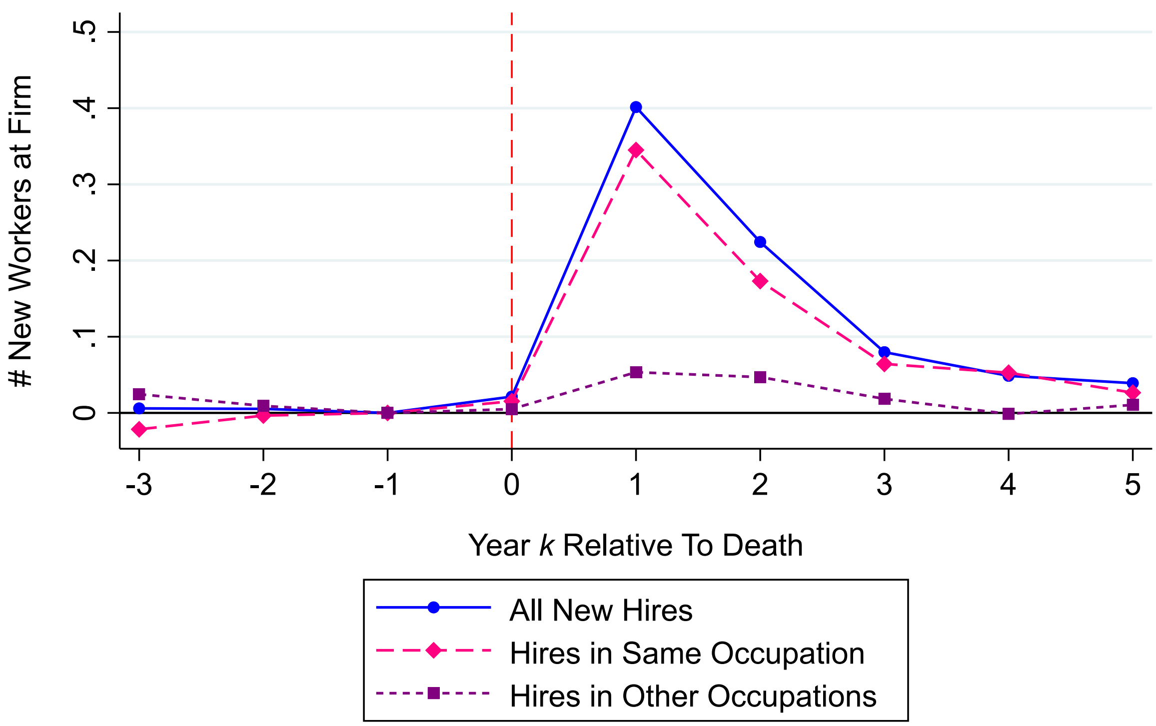
Table A-4.19: Heterogeneity in Effects on Hours per Week

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.

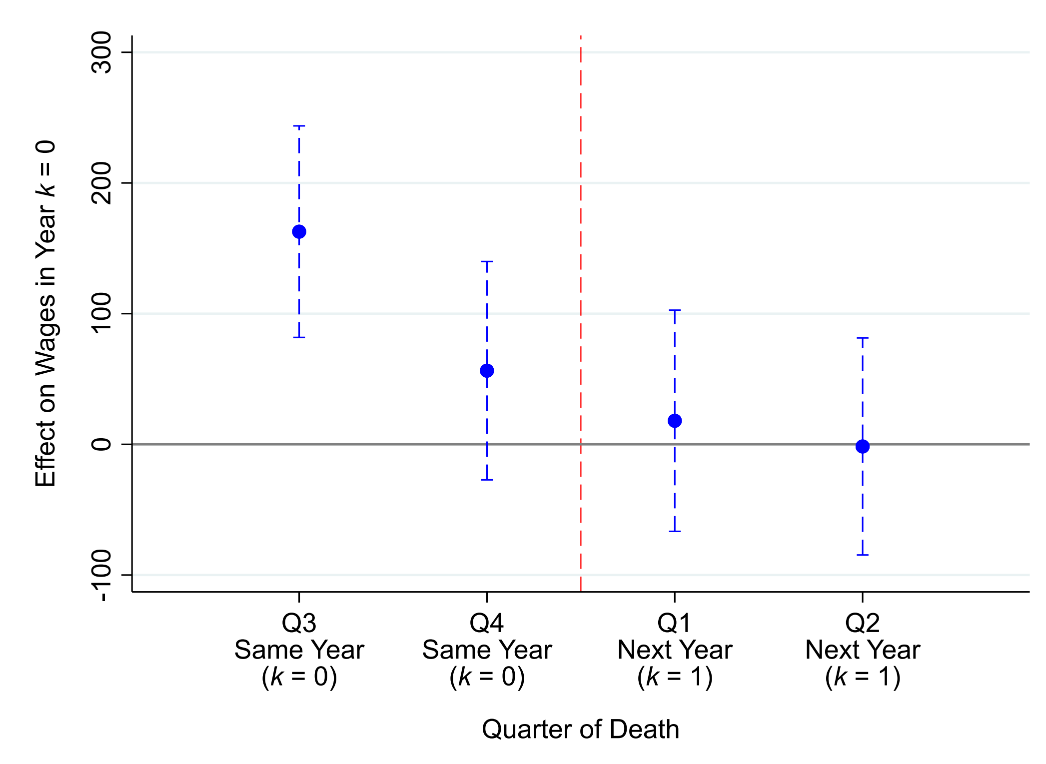
A-4.2 Additional Figures

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



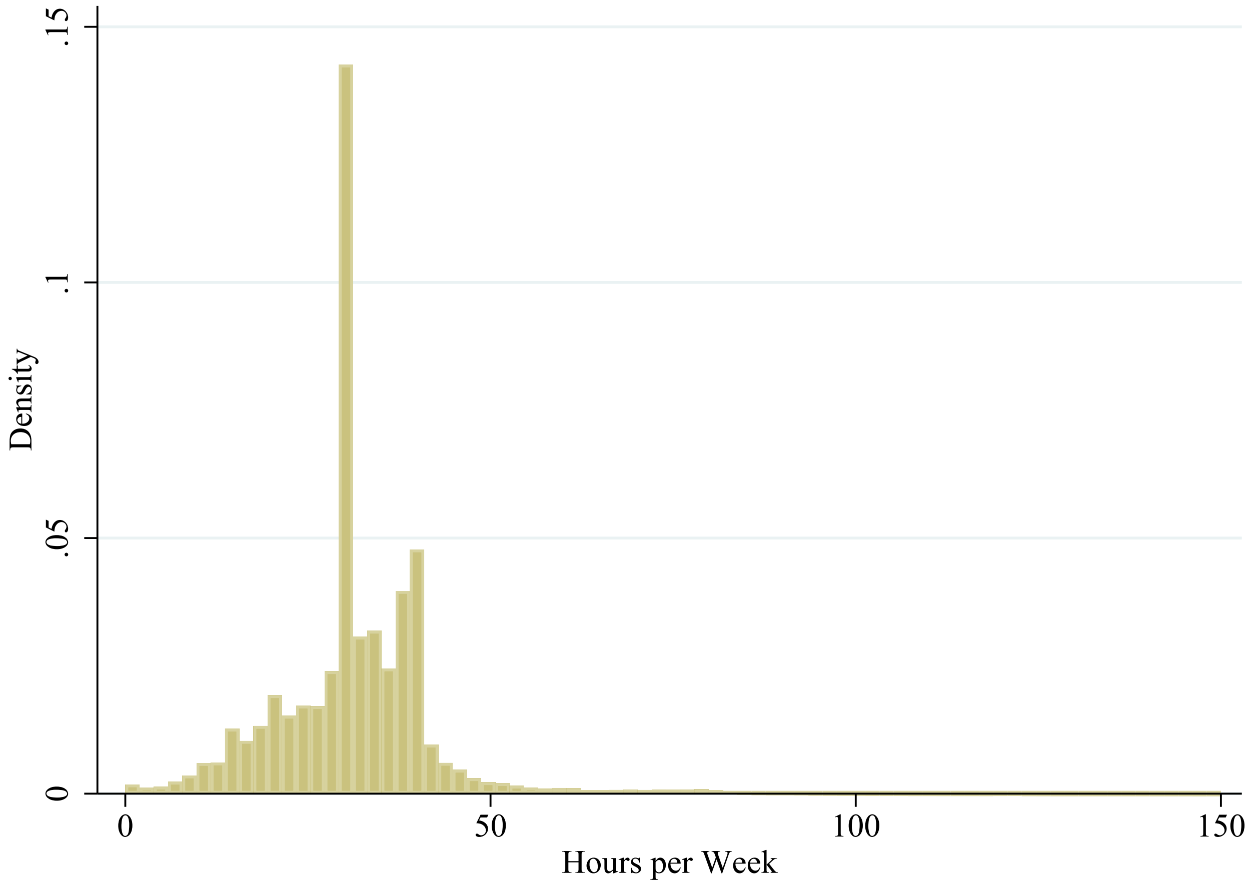
Note: The figure shows the treatment effect on hiring of new workers and decomposes the effect on total hiring (All New Hires) into hiring in the same 5-digit occupation as the deceased worker (Hires in Same Occupation) and hiring of workers into other occupations (Hires in Other Occupations). The treatment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

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



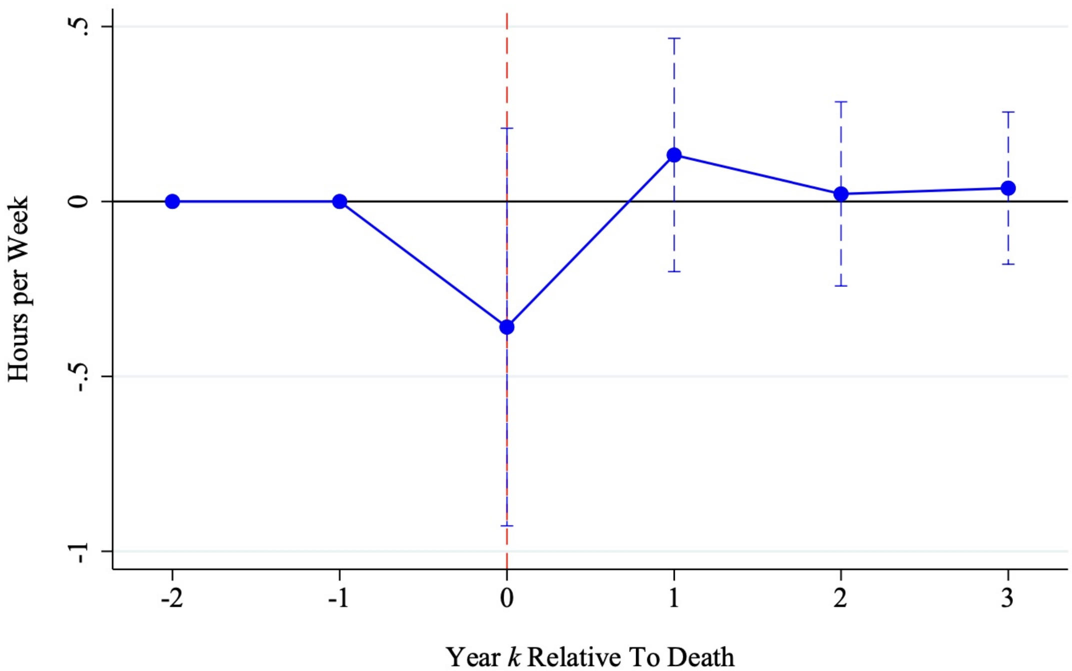
Note: The figure presents results of a difference-in-differences regression of wages in year k=0 on treatment status interacted with dummies for the quarter of death of the deceased worker in the treatment group. The positive and statistically significant coefficients for wage effects in year 0 of deaths 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.

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.

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.