Wage Rigidity and Employment Outcomes: Evidence from Administrative Data *

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Abstract

This paper examines the relationship between downward nominal wage rigidity and employment outcomes using a novel linked employer-employee dataset from Germany. The estimates suggest wage rigidity prevents 24.5 percent of counterfactual wage cuts, with a standard deviation of 23.5 percent across establishments. An establishment with the average level of wage rigidity is predicted to have a 0.7 percentage point increase in the layoff rate, a 1.8 percentage point reduction in the quit rate, and a 1.3 percentage point reduction in the hire rate relative to an establishment with no measured wage rigidity. Those patterns are consistent with the predictions of a structural model. A counterfactual policy simulation suggests that inflation can "grease the wheels" of the labor market by facilitating real wage cuts even when nominal wage cuts are costly to achieve.

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> You say, "We know from repeated experience that the money price of labour never falls till many workmen have been for some time out of work." I know no such thing; and, if wages were previously high, I can see no reason whatever why they should not fall before many labourers are thrown out of work. All general reasoning, I apprehend, is in favour of my view of this question, for why should some agree to go without any wages while others were most liberally rewarded?
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> *Letter of David Ricardo to Thomas Malthus, 1821*

1 Introduction

A perennial debate in economics concerns the extent to which difficulty reducing nominal wages affects employment outcomes. This paper uses a novel dataset to estimate the extent of wage rigidity at a sample of West German establishments. It then examines the relationship between establishment-level wage rigidity and employment outcomes, specifically layoff, quit, and hire rates. The results are consistent with the predictions of a theoretical model of establishment decision-making in the face of downward nominal wage rigidity (simply "wage rigidity" hereafter). Establishments with more rigid wages exhibit higher layoff rates and lower quit and hire rates.

The data are particularly well-suited for the task of estimating establishment-level wage rigidity, as they contain total compensation histories for every worker at each of the sampled establishments. Those compensation histories are taken from administrative data and should be free of measurement error. The estimates suggest that wage rigidity prevents 24.5 percent of wage cuts at the average establishment, with a standard deviation of 23.5 percent across establishments. Establishments in the construction and transportation supersectors display the least wage rigidity, with average levels of 3.2 percent and 11.5 percent of wage cuts prevented, respectively. Establishments in the public administration supersector display the most wage rigidity, with an average level of 45.9 percent of wage cuts prevented.

The paper introduces a measure of wage rigidity that synthesizes elements of the "histogram-location" and "symmetry" approaches popular in the literature and is suitable for establishment-level analysis. There are three major advantages to the proposed estimator. First, it uses both cross-sectional and time variation in the position of the wage change distribution to identify wage rigidity, rather than relying solely on cross-sectional variation within each period. Second, in contrast to typical histogram-location approaches, the proposed estimator uses wage changes both above and below the median wage to estimate the counterfactual distribution of wages in the absence of wage rigidity. Third, the estimator performs well regardless of whether the median wage change is above or below zero, a situation that arises with non-trivial frequency at the establishment-year level.

The paper also establishes a clear empirical relationship between wage rigidity and employment outcomes. Because the data allow for the observation of employment flows at the individual level, including into and out of unemployment, layoffs, quits, and hires may be imputed with minimal assumptions. An establishment with the sample-average level of wage rigidity is predicted to have a 0.7 percentage point higher layoff rate, a 1.8 percentage point lower quit rate, and a 1.3 percentage point lower hire rate than an establishment with no wage rigidity.[1] Wage rigidity amplifies layoffs at establishments with shrinking revenues and dampens hires at establishments with growing revenues. Given a one standard deviation decrease in revenue growth, an establishment with average wage rigidity is predicted to increase its layoff rate by 1.5 percentage points more than an establishment with no wage rigidity. Given a one standard deviation increase in revenue growth, an establishment with average wage rigidity is predicted to increase its hire rate by 2.6 percentage points less than an establishment with no wage rigidity.

The individual-level wage data used in this paper is a measure of total compensation that includes base salary, bonuses, and other forms of compensation, which is a significant advantage relative to much of the previous literature. Due to data limitations, many previous studies focus on wage rigidity in base pay only. However, establishments may circumvent wage rigidity in base pay by altering bonuses and other forms of compensation. Thus, a complete examination of the relationship between wage rigidity and employment outcomes should include a measure of total compensation, as this paper does. It is worth bearing this distinction in mind when comparing the estimates of wage rigidity presented in this paper to estimates from other papers.

Using the empirical results to estimate the structural model via indirect inference suggests that wage rigidity reduces the average establishment's revenues by 2.6 percent and that the real resource cost of wage cuts is on average 0.9 percent of revenues. The estimates suggest that the average establishment faces a per-worker menu cost of 603 euros annually of cutting nominal wages. A counterfactual policy simulation implies that inflation mitigates the resource costs of wage cuts. The reduction in revenue relative to a case with no wage rigidity falls from 3.0 percent with an inflation rate of 0 percent to 1.3 percent at an annual inflation rate of 5 percent. The real resource cost of wage cuts as a proportion of revenues also falls from 1.1 percent with an inflation rate of 0 percent to 0.4 percent with an inflation rate of 5 percent. Higher inflation also reduces the simulated layoff rate and increases the quit and hire rates.

Several previous studies have documented the existence of wage rigidity in microeconomic datasets. Prominent examples using U.S. data include Card and Hyslop (1997) and Kahn (1997). Kahn (1997) estimates that wage earners experience nominal wage reductions 47 percent less often than they would in the absence of wage rigidity. Daly and Hobijn (2013) show that the proportion

[1]For comparison, the sample average layoff rate is 4.5 percent, the sample average quit rate is 9.2 percent, and the sample average hire rate is 17.2 percent.

of workers reporting a zero nominal wage change in the United States increased in the recent recession, from 12 percent in 2006 to 16 percent in 2011. Lebow, Saks, and Wilson (1999) estimate that wage rigidity prevents 30 percent of reductions in total nominal compensation that would otherwise occur, even accounting for benefits such as cash bonuses and health insurance. Using European data, Knoppik and Beissinger (2009) conclude that wage rigidity prevents 37 percent of counterfactual wage cuts in the Euro area, and 28 percent of wage cuts in Germany specifically. Dickens et al. (2007) examine evidence in the United States and 15 European countries, and find that the fraction of workers covered by wage rigidity is 28 percent on average, ranging from 4 percent in Ireland to 58 percent in Portugal.

It has been difficult, though, to establish a link between wage rigidity and employment outcomes. Card and Hyslop (1997) find that "...nominal rigidities have a small effect on the aggregate economy...," while Altonji and Devereux (2000) report, "Our estimates of the effect of nominal wage rigidity on layoffs and promotions ... are too imprecise for us to draw any conclusions." Daly and Hobijn (2013) find that their model of nominal wage rigidity generates wage dynamics that are consistent with recent U.S. data, although their use of the Current Population Survey prevents them from studying the micro-level relationship between wage rigidity and employment outcomes. Akerlof, Dickens, and Perry (1996) find that wage rigidity makes a statistically insignificant difference in macroeconomic time series estimates of a Phillips Curve equation in the postwar period. Lebow et al. (1999) estimate that the non-accelerating inflation rate of unemployment is positively correlated with inflation, contrary to what would be predicted by an important role for nominal wage rigidity. They describe the apparent contradiction between the evidence on the extent of wage rigidity and the lack of evidence that it affects employment outcomes as a "micro-macro puzzle".

An exception to this pattern is Kaur (2012), who finds strong causal effects of wage rigidity on employment levels in informal agricultural labor markets in India. Additionally, Olivei and Tenreyo (2007, 2010) show that rigidities in wage setting can affect the real economy, documenting that the effects of monetary policy shocks differ over the course of the year in countries where there is strong seasonality in wage setting but not in countries where wage-setting decisions are spread evenly throughout the year.

Two possible solutions to the micro-macro puzzle have been proposed. Barro (1977) argues that in a long-term employment relationship, the wage at a particular point in time is less important than the path of wages over the life of the relationship. Therefore, apparently rigid wages may reflect optimal long-term contracting rather than difficulties in wage adjustment, and may not have meaningful implications for employment outcomes. Elsby (2009) notes that forward-looking, wage-setting firms will compress wage increases in the presence of wage rigidity. Smaller wage increases in good times reduce the need for wage cuts in the face of an adverse shock.

The model in this paper incorporates the Elsby (2009) wage-compression effect, as it examines the optimal dynamic wage and employment decisions of an establishment that faces a real resource cost of cutting nominal wages. When this cost is large enough, the establishment will not cut wages in response to a negative shock to the marginal revenue product of labor, but will lay off workers instead. However, the effect of wage rigidity is not limited to the layoff margin of employment adjustment. When wage rigidity prevents workers' wages from being cut, the workers will be less likely to quit. Prospective difficulties in cutting wages in the future also reduce forward-looking establishments' incentive to hire workers in the present. Bils et al. (2014) propose a search and matching model in which sticky wages also reduce hiring when existing workers' wages are higher than the firm would optimally choose. The model in this paper predicts that wage rigidity has meaningful effects on short-run employment outcomes, consistent with the empirical results.

The paper proceeds as follows: Section 2 presents a model of establishment decision-making in the presence of wage rigidity and derives predictions for the effects of wage rigidity on layoffs, quits, and hires. Section 3 provides an overview of the data set and basic descriptive statistics. Section 4 introduces a method of measuring wage rigidity at the establishment level and describes the distribution of wage rigidity across establishments in the sample. Section 5 estimates the empirical relationship between wage rigidity and layoffs, quits, and hires. Section 6 uses those results to estimate the theoretical model by indirect inference, quantifies the costs of wage rigidity to establishments, and conducts a series of counterfactual policy simulations under various levels of the inflation rate. Section 7 concludes.

2 Model of Establishment Decision Making with Wage Rigidity

This section examines the dynamic wage and employment policies of a single establishment with heterogeneous worker types facing an imperfectly competitive labor market.[2] The establishment's goal is to maximize its discounted stream of expected future profits. The establishment experiences shocks to its marginal revenue product of labor and faces costs of adjusting its stock of labor and wage rate.

[2]The analysis refers to an establishment rather than a firm to be consistent with the data set, which provides establishment identifiers rather than firm identifiers. Theoretically, however, the analysis would apply equally as well to a firm's problem.

2.1 Establishment Environment

The establishment has infinite life and uses one input to production, labor, of which there are J distinct types. The establishment maximizes its discounted stream of expected per period profits, which are given as:

$$\Pi = \sum_{j=1}^{J} \left(a_j n_j^{\alpha} - w_j n_j - c_h(h_j, n_{j,-1}) h_j - c_\ell \ell_j - g(w_j, w_{j,-1}) n_j \right)$$

where n_j is the stock of type j labor used in production, α governs returns to scale, and w_j is the wage rate for type j labor. h_j and ℓ_j are the number of type j employees the establishment hires and lays off, respectively. $c_h(\cdot)$ is a per employee hiring cost function and c_ℓ is the cost per layoff. a_j is a stochastic process that shifts the marginal revenue product of labor.[3] a_j is the product of an establishment-wide productivity level z and a type j productivity level u_j.

Downward nominal wage rigidity enters the model through the wage adjustment cost function, $g\left(w_j, w_{j,-1}\right)$, which is specified in per-employee terms as a polynomial in nominal wage reductions:

$$\begin{aligned} g\left(w_j, w_{j,-1}\right) = {} & \lambda_0 \mathbb{1}_{(1+\pi)w_j < w_{j,-1}} + \lambda_1 \left(w_{j,-1} - (1+\pi)w_j\right) \mathbb{1}_{(1+\pi)w_j < w_{j,-1}} \\ & + \lambda_2 \left(w_{j,-1} - (1+\pi)w_j\right)^2 \mathbb{1}_{(1+\pi)w_j < w_{j,-1}} \end{aligned} \tag{1}$$

λ_0 represents a fixed menu cost of cutting wages, while λ_1 and λ_2 represent linear and quadratic costs of wage cuts, respectively. π represents the deterministic rate of price inflation. Both w_j and $w_{j,-1}$ are specified in real terms, but the establishment bears costs only when it cuts nominal wages. The nominal wage cut from the previous period to the present period is last period's real wage, $w_{j,-1}$, less this period's real wage, w_j, times the increase in the price level $1+\pi$, when this difference is negative, and zero otherwise.[4] Thus, the cost of wage adjustment, $g(\cdot)$, is positive when nominal wages are cut and zero otherwise. The cost of cutting nominal wages gives rise to downward nominal wage rigidity in the model. The function $g(\cdot)$ is the only place that nominal variables enter the model. Otherwise, the establishment cares exclusively about real payoffs, and all variables above are specified in real terms.

The model is agnostic regarding the precise mechanism generating wage rigidity. Multiple sources of wage rigidity have been proposed in the literature. Bewley (1999) emphasizes that wage

[3] a_j may be conceptualized either as type j's level of labor productivity or as the level of its output price; the remainder of the paper refers to a_j as productivity for concreteness' sake.

[4] Denoting the price level in period t as p_t, the nominal wage in period t is then $p_t w_t$ and the nominal wage in period $t-1$ is $p_{t-1} w_{t-1}$. Thus, a worker experiences a nominal wage cut if and only if $p_t w_t < p_{t-1} w_{t-1} \iff \frac{p_t}{p_{t-1}} w_t < w_{t-1} \iff (1+\pi) w_t < w_{t-1}$.

cuts may reduce morale, thereby lowering worker productivity. Similarly, Elsby (2009) and Kaur (2012) both model wage rigidity as arising from reductions in morale associated with wage cuts. Hall and Milgrom (2008) and Christiano, Eichenbaum, and Trabandt (2013) emphasize the role of the bargaining process between employers and workers in insulating wages from business cycle conditions. The sources of wage rigidity remain a topic of discussion in the literature. However, the model here focuses on the consequences of wage rigidity rather than its sources.

The establishment's stock of type j labor evolves according to the equation:

$$n_j \;=\; n_{j,-1} - \delta(w_j) n_{j,-1} + h_j - \ell_j$$

where $\delta(w_j)$ is the quit rate of type j labor and $h_j, \ell_j \geq 0$. The establishment faces an imperfectly competitive labor market for each type of labor. The quit rate of type j labor is given by the function

$$\delta\left(w_j\right) \;=\; \bar{\delta}\left(\frac{w_j}{\overline{w}}\right)^{-\gamma}, \quad \gamma > 0 \tag{2}$$

where $\bar{\delta}$ is the economy-wide average quit rate. The quit rate is decreasing in the wage rate, w_j. γ governs the degree of competition in the labor market: as γ increases, the quit rate becomes more sensitive to wages. In the limit as γ approaches infinity, the labor market becomes perfectly competitive.

The establishment faces a cost per hire given by the function

$$c_h(h_j, n_{j,-1}) \;=\; \phi_1\left(\frac{h_j}{n_{j,-1}}\right) + \phi_2\left(\frac{h_j}{n_{j,-1}}\right)^2 \tag{3}$$

The quadratic hiring cost function allows for increasing or decreasing returns to scale in the hire rate. Most studies of hiring costs indicate that they are subject to decreasing returns to scale, for instance Shapiro (1986), Blatter, Muehlemann, and Schenker (2012) and Muehlemann and Pfeifer (2013).

2.2 Solution to the Establishment's Problem

Because the establishment's profit function is a linear summation of the individual type j profit functions, the dynamic optimization problem can be written separately for each type of labor. For each labor type j, the establishment chooses the wage rate, level of hires, and layoffs to solve the

following dynamic optimization problem:

$$\begin{aligned} V_j\left(z, u_j, w_{j,-1}, n_{j,-1}\right) &= \max_{w_j, h_j, l_j} a_j n_j^{\alpha} - w_j n_j - c_h(h_j, n_{j,-1}) h_j - c_\ell \ell_j \\ &\quad -g(w_j, w_{j,-1}) n_j + \beta E\left[V_j\left(z', u_j', w_j, n_j\right)\right] \end{aligned} \tag{4}$$

subject to

$$\ln a_j = \ln z + \ln u_j \tag{5}$$

$$\ln z = (1-\psi_z)\ln \bar{z} + \psi_z \ln z_{-1} + \varepsilon_z,\ \varepsilon_z \sim N\left(0, \sigma_z^2\right) \tag{6}$$

$$\ln u_j = (1-\psi_u)\ln \bar{u} + \psi_u \ln u_{j,-1} + \varepsilon_{u_j},\ \varepsilon_{u_j} \sim N\left(0, \sigma_{u_j}^2\right) \tag{7}$$

$$n_j = \left(1-\delta\left(w_j\right)\right) n_{j,-1} + h_j - \ell_j \tag{8}$$

$$h_j, \ell_j \geq 0 \tag{9}$$

The Bellman equation has 4 state variables: establishment-level productivity, z, labor type j-specific productivity u_j, last period's type j wage rate, $w_{j,-1}$, and last period's type j labor stock, $n_{j,-1}$. As specified in equations 6 and 7, both productivity levels evolve according to a mean reverting, $AR(1)$ process. The errors ε_z and ε_{u_j} are assumed to be independent.

The model solution uses standard value function iteration techniques to find the establishment's value and policy functions. The method of Tauchen (1986) approximates the autoregressive process for the productivity levels z and u_j. The model estimation strategy uses the empirical results from section 5 of the paper. Thus, a description of the model estimation is deferred until section 6.

2.3 Establishment Policy Functions and Simulations

Figure I displays the establishment's policy functions in the case of perfectly flexible wages, using the parameters decribed in section 6 but setting the cost of wage cut parameters λ_0, λ_1, and λ_2, to zero. Panel A illustrates the establishment's wage policy function. The establishment pays lower wages when last period's employment level is higher. With a higher previous level of employment, the establishment can tolerate a higher quit rate while retaining enough employees to meet its desired employment level, reducing the incentive to pay high wages. Panel B illustrates the establishment's employment policy function. As expected, the establishment's desired employment level increases with productivity and the last period's level of employment, but does not vary with the last period's wage. Panel C illustrates the establishment's quit rate policy function, which the establishment controls deterministically by setting the wage rate. The quit rate policy function varies inversely with the wage policy function. It is increasing in last period's employment level and decreasing with productivity but does not vary with the previous wage. Panel D illustrates the

establishment's layoff policy function. In the absence of wage rigidity, the establishment never finds it optimal to lay off employees: it is always more profitable to lower wages, thus inducing additional quits, when employment is greater than desired. A key feature of figure I is that when wages are perfectly flexible, all policy functions are independent of the previous period's wage.

Figure II illustrates the establishment's policy functions with wage rigidity.[5] Panel A shows the establishment's wage policy function. The flat portion of the policy function towards the front of the figure is the area where wage rigidity is not binding because the optimal new wage is above the previous period's wage. The upward sloping portion is the area where wage rigidity binds and the establishment sets the current period's nominal wage equal to the previous period's nominal wage.

Panel B shows that the establishment's employment policy continues to be increasing in the previous period's employment level. However, the optimal employment level now depends on the previous period's wage. When wage rigidity binds, the resulting higher wages discourage the establishment from employing as many workers.

Panel C illustrates that the establishment's quit rate policy function remains inversely related to the wage policy function, consistent with equation (2). As before, the quit rate increases in last period's employment level. However, with rigid wages, the quit rate decreases with the previous period's wage in the area where wage rigidity is binding. The higher wages in this area of the state space induce fewer quits relative to the case with no wage rigidity.

Panel D shows that, in contrast to the policy functions in figure I, an establishment with rigid wages sometimes finds it optimal to lay off workers. Layoffs are never optimal in areas where wage rigidity does not bind, but where wage rigidity binds, the establishment responds by laying off workers. In those cases, the establishment finds it more profitable to lay off workers than to pay the cost of cutting nominal wages. This result is consistent with the intuition that wage rigidity leads to layoffs that would not occur with perfectly flexible wages.

Figure III displays a simulated wage change histogram in the case of no wage rigidity. As expected, the histogram is widely dispersed around the median and roughly symmetrical. Wage cuts are as prevalent as would be expected given a symmetrical wage change distribution. Figure IV displays a simulated wage change histogram in the case of rigid wages.[6] The distribution of wage changes is notably compressed relative to the case of flexible wages and clearly asymmetrical. The portion corresponding to wage cuts is visibly compressed relative to the portion corresponding to wage increases.

Figure V presents results from simulating the model holding all parameters fixed except the wage rigidity parameters. The horizontal axis indexes the level of wage rigidity in the simulations.[7]

[5] Specifically, the cost of wage cut parameters λ_0, λ_1, and λ_2, are set to their estimated values as described in section 6.

[6] The λ parameters are again set to their estimated values from section 6.

[7] Specifically, the estimated λ parameters are each multiplied by the scale factors shown on the horizontal axis.

The simulation uses 2,000 periods and drops the first 400 periods to allow for burn-in. Panel A shows the estimated level of wage rigidity using the estimator described in section 4.1, which is the same estimator applied to the actual data in section 5. Panel A shows that estimated wage rigidity increases with the actual level of wage rigidity in the model. Panel B shows the average layoff rate, which increases with wage rigidity. Panels C and D illustrate the average quit and hire rates, respectively, which both decrease with wage rigidity. Wage rigidity reduces the quit rate by occasionally "holding up" wages above their flexible level, thereby reducing worker turnover. The slower pace of worker turnover reduces the establishment's need to hire new workers as well. Forward-looking establishments also realize that if they hire workers in good times, they may have to pay the costs associated with wage rigidity, either from cutting nominal wages or from laying off workers, in response to future negative shocks.[8]

Therefore, the model predicts that establishments with more rigid wages should exhibit:

1. Higher layoff rates;
2. Lower quit rates; and
3. Lower hire rates.

Section 5 tests these three empirical predictions.

3 Data Description

3.1 Overview of Dataset

The paper employs administrative and survey data from the Research Data Centre (FDZ) of the German Federal Employment Agency (BA) at the Institute for Employment Research (IAB). The main analysis uses the Linked Employer-Employee Data of Integrated Labor Market Biographies (LIAB), matched with the annual IAB Establishment Panel Survey. The LIAB includes 5,293 West German establishments that participated in the annual IAB establishment survey each year either from 1999 through 2001 or from 2000 through 2002, and follows each such establishment every year of its existence from 1997 through 2003.[9]

The LIAB also provides complete labor market biographies for each employee liable to social security who was employed at a sampled, surveyed establishment at any point between 1997 and 2003. The data set follows these workers' entire employment, unemployment, and wage histories

[8]Because the model is stationary, it is theoretically possible that the hire rate will increase with wage rigidity if the increase in the layoff rate is larger than the decrease in the quit rate. However, this situation does not arise when realistic parameter values are used in the model.

[9]The East German establishments in the sample were excluded from the analysis.

from 1993 through 2007, even if the workers move to an establishment outside the sample. The LIAB also provides the exact dates that an employment spell begins and ends for an employee at a given establishment.

The administrative nature of the individual worker data is an important advantage for studying wage rigidity. Establishments provide the individual worker wage data to the FDZ by law, and are subject to penalty for misreporting. Thus, the wage data for each individual should theoretically be without measurement error. Establishment identifiers and full employment samples for the surveyed establishments allow for the accurate calculation of the wage change distribution for each establishment.

Reported wages are the average daily compensation over the employment spell and include base salary and any bonuses, fringe benefits, or other monetary compensation received throughout the spell or year. Thus, the wage reported in the data corresponds more closely to a measure of total compensation than to a base wage rate. This more inclusive wage concept is a significant advantage for studying the relationship between employment adjustment and wage rigidity in light of Lebow et al.'s (1999) finding that establishments are partially able to circumvent wage rigidity by adjusting ancillary compensation.

The employment biographies provide information such as the start and end dates of each employment spell and the reason for each employment notification (e.g. end of or break in employment, required annual notification, etc.). Therefore, labor flows such as layoffs, quits, and hires may be imputed with minimal assumptions.

Additionally, the LIAB provides an extensive set of employment-related characteristics such as the type of employment spell, professional and occupational status, and white-collar versus blue collar. The worker biographies also include detailed individual characteristics, such as gender, birth year, nationality, education, and vocational training. Finally, the annual IAB Establishment Panel Survey that is linked to the LIAB provides a rich set of establishment characteristics, including information on an establishment's revenue or business volume, and the presence or absence of a work council or wage bargaining agreement.

A disadvantage is that the dataset does not contain employee-level data on hours worked; therefore, a reduction in hours may appear as a wage cut using the wage measure in the data, the daily average wage rate. The data do distinguish between part-time workers working less than half of full-time, those working more than half of full-time, and full-time workers. The wage change distributions include only workers whose hours status does not change between periods to minimize the potential for measurement error. To the extent that this error still exists, it is likely to make wages appear less downwardly rigid than in the absence of hours variation.

Another disadvantage of the dataset is that reported compensation is top-censored at the contribution limit for the German social security system. Top-censoring affects roughly 7 percent of

workers in the sample; the analysis excludes these workers from the sample for the purpose of estimating wage rigidity, but not for the purpose of calculating employment flows.[10]

The analysis also uses the Establishment History Panel (BHP) as an additional dataset. The BHP includes industry classification codes and state- and distrcit-level location identifiers for each establishment. In additon, the BHP contains an extension file with information on establishment births, deaths, and reclassifications. Supplementary data in this extension allows for the identification of establishment closures that are likely to be spin-offs or takeovers as opposed to true closures.

The final dataset used in the paper is the Sample of Integrated Labor Market Biographies (SIAB). The SIAB provides complete labor market biographies for a 2 percent random sample of all employees liable to social security. However, the SIAB does not provide worker biographies for all workers at a sampled establishment as in the LIAB, nor is it linked to the Establishment Survey Panel. Therefore, the paper focuses on the LIAB for the main analysis. However, because the SIAB is a representative sample of the German workforce, the dataset provides an opportunity to examine aggregate labor market statistics in section 3.3.

3.2 Descriptive Statistics

The analysis restricts the sample to the years 1997 through 2003, the period for which the data includes worker biographies for all workers at the sampled establishments. The analysis includes workers ages 20 through 60. The main unit of observation is the establishment-year. An establishment-year is excluded if the establishment has less than 50 employees or 10 valid wage changes in the year. An establishment is excluded altogether if it does not meet the criteria above for at least three years. Additionally, the analysis requires data on establishment revenues in both the current and previous years in order to calculate the establishment's change in revenue. These restrictions leave 2,250 establishments for the analysis.

Layoff, quit, and hire rates are measured as fractions of the establishment's total workforce as of December 31st of the preceding year. Following a convention for distinguishing involuntary layoffs and voluntary quits in the worker biographies similar to that of Blein and Rudolph (1989) and Haas (2000), a layoff is defined as an interruption between employment spells that results in the employee flowing into unemployment before the beginning of another employment spell, as indicated by receipt of unemployment assistance during the intervening period. Conversely, a quit is defined as an employment interruption that does not contain an unemployment spell and results in an employee flowing into another job without receipt of unemployment assistance. The begin-

[10]The exclusion is necessary because workers with earnings above the contribution limit are all assigned the same top-coded wage in a given year. Therefore, these workers' wage changes would not reflect their actual earnings but instead the change in the yearly contribution limit.

ning of a new employment spell is classified as a hire if the employee's immediately preceding spell was either unemployment or employment at another establishment.[11] In the data, there are many instances of a spell reported as ending, but after which the worker resumes employment at the same establishment nearly immediately without collecting unemployment assistance. These occurences are classified as neither quits nor hires if the break between spells is less than 28 days. A separation is classified as neither a layoff nor a quit if the worker's biography contains neither a subsequent employment spell nor subsequent receipt of unemployment assistance (for instance, if the worker dies).[12] This situation arises in less than one percent of separations.

Table I shows the descriptive statistics of the layoff, quit, and hire rates for the sample of establishments from 1997 through 2003. The average annual layoff rate over the period is 4.5 percent with a standard deviation of 9.2 percent across establishment-years. The average annual quit rate over the period is 9.2 percent with a standard deviation of 14.7 percent. The average annual hire rate is 17.2 percent with a standard deviation of 32.7 percent. The average establishment employs 549 workers, versus 219 workers for the median establishment. The average nominal wage is 102.40 euros per day, with a standard deviation of 66.37 euros per day. The average wage expressed in year 2000 euros was 101.81 euros per day, with a standard deviation of 65.66 euros per day.[13]

The empirical strategy described in section 5 uses changes in establishment revenues to proxy for shifts in the marginal revenue product of labor. Each year, the survey asks each establishment to provide its total business volume (or sales) in the preceeding fiscal year (i.e. from January 1 through December 31).[14] The average establishment-year revenue growth in the sample is 3.5 percent with a standard deviation of 20.6 percent.

[11] A fourth possibility for employment adjustment is that of a "spin", which can take the form of either an inflow or an outflow. Spin employment flows are those that involve employment movements either between establishments within a firm or a merger or acquisition of two establishments from different firms. An example of an employment movement between establishments covered under the former description is that of an establishment closure where a large proportion of employees from the closed establishment moves directly to another establishment within the same firm. The FDZ provides an extension file on establishment births, deaths, and reclassifications that allows for the identification of spin employment flows. Because the study focuses on the relationship between wage rigidity and the traditional employment flows, spin flows are excluded from the analysis.

[12] The establishment-level anlysis considers the period 1997 through 2003, but the worker biographies span the period 1993 to 2007, so most worker biographies extend beyond the end of the analysis period.

[13] For the purposes of calculating these descriptive statistics, wages were imputed for top-coded earners using a procedure provided by the FDZ.

[14] While the sample only covers establishments with full employment biographies from 1997 through 2003, the survey spans from 1993 through 2008. The 2004 survey records the establishment's business volume from 2003, the 2003 survey records business volume from 2002, etc.

3.3 Aggregate Wage Change Distributions

The wage data from the SIAB provides a representative overview of wage changes for job stayers during the period 1997 through 2003. Figure VI shows the annual aggregate nominal wage change distributions for this period. The plot labeled 2000 represents the distribution of wage changes from 1999 to 2000, et cetera.

Four conclusions are visually evident from observing the nominal wage change histograms and are confirmed through simple tabulations. First, the aggregate nominal wage change distributions exhibit a clear spike at the histogram bin containing a nominal wage change of zero (or the "zero bin" for short). The proportion of nominal wage changes in the zero bin ranges from 11.32 percent to 15.45 percent, with an average of 12.35 percent. Second, a nominal wage change of zero is the most common nominal wage change over the sample period. Third, while nominal wage cuts certainly occur, they are less frequent than nominally zero and nominally positive wage changes. Further, it appears as if a part of the nominally negative portion of the wage change distribution is "missing" when compared to its nominally positive counterpart. From 1997 through 2003, the fraction of workers receiving a nominal wage cut ranges from 14.88 percent to 21.32 percent, with an average of 18.46 percent.

Finally, the aggregate nominal wage change distributions exhibit a significant "fall-off" in density from the zero bin to the nominally negative bin immediately to the left of zero. For example, in the year 2003, the zero bin contains 15.45 percent of all wage changes compared to only 4.84 percent in the bin immediately to the left, a fall-off of 10.61 percentage points. Throughout the sample period, the fall-off in density from the zero bin to the bin immediately to the left ranges from 6.17 to 10.61 percentage points and averages 7.90 percentage points. For comparison, the next largest average fall-off between any two histogram bins is 2.91 percentage points and only eight bins exhibit an average fall-off of more than one percentage point. This evidence suggests the existence of downward nominal wage rigidity in the aggregate German economy. The paper now turns to measuring the degree and extent of wage rigidity across German establishments.

4 Estimating Wage Rigidity

4.1 Methodology

Previous studies have proposed several methods of measuring downward nominal wage rigidity. However, those studies have measured wage rigidity at the aggregate level, whereas this study measures wage rigidity at the establishment level. The small size of many of the establishments in the sample poses a problem for these approaches in the context of this paper. The approach in this paper takes elements from Card and Hyslop (1997) and Kahn (1997), modified for the context of

much smaller samples. Figures VII through X illustrate the approach.

For each establishment i, let m_{it} represent the median wage change from time $t-1$ to time t expressed in percentage points. Then measure the proportion of wage changes in each year in one percentage point wide bins. Let $prop_{ijt}$, for $j \in \{-10, -9, -8, ..., -1, 1, ..., 8, 9, 10\}$, denote the size of the bin that is between j and $j+1$ percentage points away from the median wage change for that year. Figure VII illustrates these measurements for a simulated establishment.[15] For example, $j = -1$ represents the bin between the median wage change and the median wage change minus one percent in each year, whereas $j = 1$ represents the bin between the median wage change and the median wage change plus one percent. In year 1, the median wage change is 2.9 percent, and bin $j = -1$ contains wage changes between 1.9 percent and 2.9 percent, whereas bin $j = 1$ contains wage changes between 2.9 percent and 3.9 percent. The median wage change always separates bins $j = -1$ and $j = 1$. However, the bin j containing nominal zero will vary with the median wage change over time. For instance, in year 1 the nominal wage change of zero lies in bin $j = -3$, which includes wage changes between -0.1 percent and 0.9 percent; in year 2, the median nominal wage change is 6.8 percent, and the nominal wage change of zero lies in bin $j = -7$. The analysis excludes all bins more than 10 percentage points from the median each year.

For each establishment, estimate the regression

$$prop_{ijt} = \delta_0 + \delta_1|j| + \delta_2 j^2 + \epsilon_{it},\ j + m_{it} > 0,\ \forall t \tag{10}$$

The regression in equation (10) restricts the sample to bins that reflect nominal wage increases only, and excludes the bin containing wage changes of nominal zero, as illustrated in figure VIII. A data point in this regression is the proportion of wage changes in bin j, in year t, at establishment i. The regression pools the data across years within an establishment. Thus, for the simulated establishment in figure VIII, the regression in (10) contains 74 data points, as there are a total of 74 nominally positive wage change bins across all six years. $|j|$ and j^2 represent the linear and quadratic distances from the median wage change, respectively. Therefore, equation (10) expresses the nominally positive portion of the wage change distribution as a quadratic function of the distance from the median wage change each year.

Next, this estimated function is used to predict what the nominally negative portion of the wage change distribution would be in the absence of wage rigidity. The estimated coefficients from equation (10) are used to predict the values $\widehat{prop}_{ijt}$ for the bins that contain negative wage changes, again excluding the bin that contains wage changes of nominal zero.[16] For example, in

[15] The data user agreement with the FDZ prohibits displaying the wage change histograms for a single establishment, necessitating the use of a simulated establishment for the illustration.

[16] In cases where $prop_{ijt}$ would be predicted to be negative, $\widehat{prop}_{ijt}$ is set to zero. Using a Tobit regression in this step does not change the results in a meaningful way.

year 1 of figure IX, proportions are predicted for bins $j = -4$ through $j = -10$.

These predicted values are used to estimate the regression

$$prop_{ijt} = \gamma_i \times \widehat{prop}_{ijt} + u_{ijt},\ j + m_{it} + 1 < 0,\ \forall t \tag{11}$$

Equation (11) regresses the observed proportion of wage changes in bins corresponding to nominal wage cuts on the proportions that would be predicted from the regression in equation (10). Figure X illustrates how the regression operates. The dark bars in the nominally negative portion of the distribution represent the observed proportion of wage changes in these bins, while the light bars represent the predicted proportions of wage changes in these bins. $\hat{\gamma}_i$ represents the fraction of predicted wage cuts observed in the data. The measure of establishment-level wage rigidity is the proportion of counterfactual wage cuts that are "missing" from the data and is calculated as

$$\widehat{wr}_i = 1 - \widehat{\gamma}_i \tag{12}$$

Therefore, the wage rigidity estimate in equation (12) is a time-invariant characteristic of the establishment. $\widehat{wr}_i$ has the natural interpretation that a value of 0.25 implies that 25 percent of counterfactual nominal wage cuts at establishment i were prevented by downward nominal wage rigidity over the sample period.[17]

This approach to estimating wage rigidity has three main advantages in an establishment-level context. First, it uses cross-sectional and time variation in the position of the wage change distribution to identify wage rigidity, rather than relying solely on cross-sectional variation within each period. Second, in contrast to typical histogram-location approaches to estimating wage rigidity in the literature, this wage rigidity estimator uses wage changes both above and below the median to estimate the counterfactual distribution. Third, it performs well regardless of whether the median wage change is above or below zero, a situation that can be problematic for estimators that rely only on cross-sectional variation in the wage change distribution within a period. This situation arises in 8.02 percent of the establishment-years in the sample.

This approach implicitly assumes that an establishment's counterfactual wage change distribution is symmetrical and has a constant variance across years. Card and Hyslop (1997) argue that, "...symmetry is a natural starting point for building a counterfactual distribution. ...if the individual wage determination process is stationary, then symmetry holds." It is also worth noting that the aggregate German wage change distributions shown in appendix B in section B appear to be roughly symmetrical around the median in the high inflation years of the late 1970s and early 1980s. When inflation is high, a smaller proportion of the wage change distribution is pushed against nominal

[17]Nothing in this procedure prevents $\widehat{wr}_i$ from being negative. A value for $\widehat{wr}_i$ of -0.25 would imply that there are 25 percent more wage cuts in the data than would be predicted by the distribution of nominally positive wage changes.

zero compared to periods of low inflation. Thus, the shape of the wage change distribution in high inflation periods is likely to be indicative of the shape of the counterfactual distribution that would prevail in the absence of downward nominal rigidity.

A potential drawback of this approach is that it also implicitly assumes the nominally positive portion of the wage change distribution is unaffected by wage rigidity in order to predict the nominally negative portion. As emphasized by Elsby (2009), theory suggests that wage rigidity should affect the nominally positive portion of the wage change distribution as well as the nominally negative portion. Specifically, wage increases should be compressed in the presence of wage rigidity. This compression is evident in simulations of the theoretical model presented in section 2, as well. Monte Carlo simulations of the estimator presented here suggest that it is unbiased both with and without compression in the wage change distribution. Intuitively, this is because the estimator only attempts to estimate the fraction of counterfactual wage cuts prevented by wage rigidity, and not their magnitudes.

The Monte Carlo simulations suggest that there is some sampling error associated with the estimator. This sampling error will lead to attenuation bias in the estimates of the association between wage rigidity and employment outcomes presented in section 5. Therefore, the estimates of these associations are likely to underestimate the strength of the true associations. Please see appendix A for a discussion of the Monte Carlo simulations.

4.2 The Distribution of Wage Rigidity in West Germany

Table II shows the mean, median, and standard devation of the distribution of wage rigidity estimates for individual establishments within the sample. The average establishment-level measure of wage rigidity is 24.5 percent, implying that wage rigidity prevents 24.5 percent of counterfactual wage cuts at the average establishment. The standard deviation of the estimates is 23.5 percent and the median is 21.8 percent. Thus, there is both a notable degree of estimated wage rigidity among establishments and significant variation across establishments.

Table II also shows the mean, median, and standard devation of the distribution of wage rigidity estimates within each of the ten supersectors of the economy to provide context as to where wage rigidity is present. The mean and median levels of wage rigidity vary widely across supersectors, with little difference between the mean and median within supersectors. The variation within supersectors, as measured by the standard deviation across establishments, ranges from 19 percent to 34 percent. Among supersectors, public administration exhibits the highest degree of wage rigidity, with an average of 45.9 percent of wage cuts prevented by wage rigidity across establishments. Administration, finance, and energy/water also display large amounts of wage rigidity, with an average of 35.5, 31.1, and 28.9 percent of wage cuts prevented, respectively. Construction, trans-

portation, and mining/manufacturing exhibit the smallest degree of average wage rigidity, with 3.2 percent, 11.5 percent, and 12.8 percent of nominal wage cuts prevented, respectively.

5 Wage Rigidity and Employment Adjustment

5.1 Empirical Approach

The predictions from the theoretical model in section 2.3 imply empirical regressions of the form:

$$y_{it} = \beta_0 + \beta_1 wr_i + X'_{it}\Upsilon + \epsilon_{it} \tag{13}$$

where the unit of observation is an establishment-year. y_{it} represents an employment adjustment variable of interest: the layoff rate, the quit rate, or the hire rate. wr_i represents the estimated percentage of wage cuts prevented by downward nominal wage rigidity, as discussed in section 4.1. X_{it} represents a vector of control variables, including a dummy for the presence of a work council, the median year-over-year percentage wage change, a set of year, state, and sector fixed effects, dummies for establishment size groups, the fraction of the workforce that is female, and controls for workforce educational attainment and occupation. Estimates of equation (13) are presented in column 1 of tables III, IV, and V, for layoffs, quits, and hires, respectively. Figures VIII, IX, and X illustrate the economic interpretation of these estimates.

It is natural to examine whether the association between wage rigidity and employment adjustment varies according to the economic shocks an establishment faces. In the theoretical model presented in section 2, layoffs are a response to negative shocks to the marginal revenue product of labor, while hires are a response to positive shocks to the marginal revenue product of labor.[18] Although the data do not permit explicit observation of marginal revenue product of labor shocks, data on revenue growth is likely to be informative about such shocks. Assuming changes in revenue growth reflect primarily shifts in the marginal revenue product of labor suggests the following additional specification for examining the relationship between wage rigidity and employment outcomes:

$$\begin{aligned} y_{it} \;=\; & \beta_0 + \beta_1 wr_i + \beta_2 posrev_{it} + \beta_3 negrev_{it} \\ & + \beta_4 \left(wr_i \times posrev_{it}\right) + \beta_5 \left(wr_i \times negrev_{it}\right) + X'_{it}\Upsilon + \epsilon_{it} \end{aligned} \tag{14}$$

The variables $posrev_{it}$ and $negrev_{it}$ denote the year-over-year percentage change in revenue; $posrev_{it}$ is set to zero when this change is negative, while $negrev_{it}$ is set to zero when this change

[18] These responses can persist over time after the initial shock.

is positive. Specifying the change in revenue this way allows the estimation of a linear spline function over revenue growth, permitting disparate associations between revenue growth and employment adjustment depending on whether revenue growth is positive or negative.[19] The variables $(wr_i \times posrev_{it})$ and $(wr_i \times negrev_{it})$ are interactions between estimated establishment wage rigidity and revenue growth, capturing possible interactions between wage rigidity and changes in revenue.

Tables III, IV, and V present three sets of results for each outcome variable. Column (1) presents estimates of equation (13). Column (2) presents estimates of equation (14) without the wage rigidity-revenue growth interaction terms. Column (3) presents estimates of equation (14) including wage rigidity-revenue growth interaction terms. All regressions are weighted by establishment-year employment. Regression weights are likely to be appropriate for two reasons: first, because the estimate of wage rigidity is likely to be less noisy at larger establishments; and second, because larger establishments employ a much larger percentage of the total workforce, and thus their behavior has a larger effect on the aggregate economy.

5.2 Layoffs

Table III shows results from the layoff regressions. In column (1), the estimated coefficient on the wage rigidity variable is 2.9 percent and statistically significant.[20] The sign is consistent with the predictions presented in section 2.3: establishments with higher degrees of wage rigidity exhibit higher layoff rates. Adding positive and negative revenue growth as regressors in column (2), the coefficient on estimated wage rigidity is again 2.9 percent and statistically significant. In column (3), which adds interactions between wage rigidity and revenue growth, the coefficient on the level of estimated wage rigidity is 2.5 percent and statistically significant. The coefficients on the uninteracted revenue growth terms are statistically insignificant, as is the coefficient on the interaction between wage rigidity and positive revenue growth. However, as suggested by the model, the coefficient on the interaction between wage rigidity and negative revenue growth is negative 19.3 percent and highly significant. Because $negrev_{it}$ enters the regression as a weakly negative number, the negative coefficient on the interaction implies that an establishment with more rigid wages exhibits more layoffs when its revenue declines than an establishment with less rigid wages.

Figure XI shows the economic interpretation of these coefficients. The horizontal axis measures the estimated level of wage rigidity for an establishment, and the vertical axis measures the predicted increase in the layoff rate for an establishment relative to the case of no wage rigidity.

[19] The specification of revenue growth as a linear spline function with a kink at zero is similar to the specification of Holzer and Montgomery (1993), who also interpret changes in sales growth as reflecting primarily shifts in demand.

[20] Unless otherwise noted, all references to statistical significance refer to the 95-percent confidence level.

The solid line in figure XI presents the economic interpretation of the layoff regression results from column (1) of table III with no revenue variables or interaction terms. An establishment with the sample average level of wage rigidity of 24.5 percent is predicted to have a 0.7 percentage point higher layoff rate than an establishment with no wage rigidity. This difference corresponds to a 15.9 percent increase over the 4.5 percent sample average layoff rate. An establishment with estimated wage rigidity of 48 percent, one standard deviation above the sample average, is predicted to have a 1.4 percentage point higher layoff rate than an establishment with no wage rigidity, an increase of 30.9 percent relative to the average.

The dashed line in figure XI presents the economic interpretation of the layoff regression results from column (3) of table III, which include the revenue variables and the interaction of the revenue variables with wage rigidity. Specifically, the line shows an establishment's predicted increase in the layoff rate relative to the case of no wage rigidity given a negative, one standard deviation (-20.6 percent) movement in revenue growth. Including the revenue interaction terms in the empirical model significantly amplifies the positive relationship between estimated wage rigidity and layoffs. An establishment with the sample average level of wage rigidity and a one standard deviation negative movement in revenue growth is predicted to have a 1.5 percentage point higher layoff rate relative to an establishment with no wage rigidity, corresponding to a 34.5 percent increase. Further, an establishment with estimated wage rigidity one standard deviation above the sample average is predicted to have a 3.0 percentage point higher layoff rate, corresponding to a 66.7 percent increase in the layoff rate relative to the sample average.

5.3 Quits

Table IV shows results from the quit regressions. In column (1), the estimated coefficient on the wage rigidity variable is -7.2 percent and statistically significant. This sign is consistent with the predictions from the theoretical model, as establishments with higher degrees of wage rigidity exhibit lower quit rates. In column (2), the coefficient on estimated wage rigidity is also -7.2 percent and statistically significant. In column (3), the coefficient on estimated wage rigidity is -5.2 percent and statistically significant. The coefficients on the interactions between wage rigidity and revenue growth imply that firms with more wage rigidity are predicted to experience fewer quits in response to an increase or a decrease in revenue, although the coefficient on the negative revenue movement interaction is not statistically significant.

Figure XII shows the economic interpretation of the coefficients in the quit rate regressions. The horizontal axis measures the estimated level of wage rigidity for an establishment, and the vertical axis measures the predicted decrease in the quit rate for an establishment relative to the case of no wage rigidity. The solid line presents the economic interpretation of the quit rate re-

gression results from column (1) of table IV with no revenue variables or interaction terms. An establishment with the sample average level of wage rigidity is predicted to have a 1.8 percentage point lower quit rate than an establishment with no wage rigidity, which corresponds to a 19.3 percent decrease relative to the 9.2 percent sample average quit rate. An establishment with one standard deviation higher than average wage rigidity is predicted to have a 3.5 percentage point lower quit rate relative to the case with no wage rigidity, which corresponds to a 38.0 percent decrease.

The dashed line in figure XII presents the economic interpretation of the quit rate regression results from column (3) of table IV, which include the revenue variables and the interaction of the revenue variables with wage rigidity. The line shows an establishment's predicted decrease in the quit rate relative to the case of no wage rigidity given a one standard deviation negative movement in revenue growth. However, the specification including the revenue interaction terms is not statistically distinguishable from the specification that does not include the revenue interaction terms, and the difference is not economically meaningful.

5.4 Hires

Table V shows results from the hire regressions. In column (1), the estimated coefficient on the wage rigidity variable is -5.3 percent and statistically significant. This coefficient implies that establishments with greater wage rigidity exhbit lower hire rates, as predicted by the theoretical model. In column (2), the coefficient on estimated wage rigidity is -5.9 percent and statistically significant. In column (3), the coefficient on measured wage rigidity is -5.3 percent and statistically significant. The coefficient on the interaction between wage rigidity and positive revenue growth has the expected negative sign and is statistically significant. Establishments with more wage rigidity are predicted to engage in fewer hires when revenue increases.

Figure XIII shows the economic interpretation of the coefficients in the hire rate regressions. The horizontal axis of figure XIII measures the estimated level of wage rigidity for an establishment, and the vertical axis measures the predicted decrease in the hire rate for an establishment relative to the case of no wage rigidity. The solid line in figure XIII presents the economic interpretation of the hire regression results from column (1) of table V with no revenue variables or interaction terms. An establishment with the sample average level of wage rigidity is predicted to have a 1.3 percentage point lower hire rate than an establishment with no wage rigidity, which corresponds to a 7.5 percent decrease relative to the 17.2 percent sample average hire rate. An establishment with one standard deviation higher than average wage rigidity is predicted to have a 2.5 percentage point decrease in the hire rate relative to the case with no wage rigidity, which corresponds to a 14.8 percent decrease in the hire rate relative to the sample average.

The dashed line in figure XIII presents the economic interpretation of the hire regression results from column (3) of table V, which include the revenue variables and the interaction of the revenue variables with wage rigidity. The line shows an establishment's predicted decrease in the hire rate relative to the case of no wage rigidity given a positive one standard deviation movement in revenue growth. Including the revenue interaction terms in the empirical model significantly amplifies the negative relationship between estimated establishment level wage rigidity and the hire rate. An establishment with the sample average level of wage rigidity and a one standard deviation positive movement in revenue growth is predicted to have a 2.6 percentage point lower hire rate than an establishment with no wage rigidity, which corresponds to a 14.8 percent decrease in the hire rate relative to the sample average. Further, an establishment with one standard deviation higher than average wage rigidity is predicted to have a 5.0 percentage point decrease in the hire rate, corresponding to a 29.1 percent decrease in the hire rate relative to the sample average.

6 Model Estimation

This paper employs a combination of methods to choose the parameters of the theoretical model described in section 2. The parameters β, π, α, $\overline{\delta}$, $\overline{w}$, γ, $\ln \bar{z}$, ψ_z, σ_z^2, $\overline{u}$, λ_1, and c_ℓ are calibrated externally or estimated directly from the LIAB microdata used throughout the paper. The parameters λ_0, λ_2, ψ_u, σ_u^2, ϕ_1, and ϕ_2 are estimated via indirect inference to match a set of simulated moments to their empirical counterparts in the LIAB microdata. The model period is taken to be one year.

6.1 Calibrated Parameters

Table VI shows the values of the calibrated parameters. The inflation rate, π, of 1.33 percent is the average rate of consumer price inflation in Germany over the period 1997 through 2003 from the World Bank's World Development Indicators. The establishment discount rate β is calibrated from the World Bank's WDI tables to match the average German real lending interest rate for the period 1997-2002. The nominal lending interest rate is defined as the bank rate that meets the short- and medium-term financing needs of the private sector, and averages 9.5 percent for the period.[21] The real interest rate is calculated as the nominal rate minus the average inflation rate of 1.33 percent. β is then calibrated as $\frac{1}{1+0.095-0.0133}$, or 0.924. The parameter c_ℓ is taken to match German redundancy costs from the World Bank's Cost of Doing Business project, taking the average of the cost for workers with 1 year of tenure and workers with 5 years of tenure. To expedite the estimation, the parameter λ_1 is set to zero. The parameter $\bar{u}$ is normalized to 1. The

[21] See http://data.worldbank.org/indicator/FR.INR.LEND/countries?page=2 for more detail. The rate is not available for 2003.

average quit rate $\overline{\delta}$ and the average daily wage $\overline{w}$ are taken directly from the microdata sample. $\overline{\delta}$ is the average quit rate across establishment-years, 9.2 percent. The average daily wage is 102.90 euros.

The returns-to-scale parameter α is chosen to match labor's average share of value added across all establishment-years in the microdata. For each establishment-year, the establishment's total wage bill is calculated from the worker biographies. The establishment's value added is calculated as total revenues minus intermediate inputs and external costs.[22] The theoretical model in section 2 abstracts from intermediate inputs, so there is no distinction in the model between revenue and value added. In the microdata, it is necessary to adjust for intermediate inputs to calculate labor's share of value added accurately. Labor's share of value added per establishment-year is simply the establishment's total wage bill divided by revenue less external costs. Averaging labor's share of value added across establishment-years yields an estimate of 0.65 for the parameter α.

The parameter γ is the elasticity of the quit rate with respect to wages in equation (2) from section 2.1. This equation is difficult to estimate directly due to its non-linearity in the wage, but a first-order Taylor's expansion yields the following linear approximation around the average wage, $\overline{w}$:

$$\delta(w) - \overline{\delta} \;\approx\; -\overline{\delta}\gamma\left(\frac{w-\overline{w}}{\overline{w}}\right) \tag{15}$$

Equation (15) expresses the deviation of the establishment-year quit rate from the average quit rate as a decreasing function of the percentage deviation of the establishment-year wage from the economy average wage.[23] Taking equation (15) to the data requires accounting for worker and establishment heterogeneity that is not present in the theoretical model.[24] A Mincer regression of individual log wages on worker and establishment observable characteristics allows for the removal of observable heterogeneity.[25] Thus, the residual from this regression provides a "cleansed"

[22]Each year, the establishment survey panel includes a question regarding the share of revenue attributable to external costs. For instance, in the 2002 survey the question read:

> What share of sales was attributed to intermediate inputs and external costs in 2001, i.e. all raw materials and supplies purchased from other businesses or institutions, merchandise, wage work, external services, rents and other costs (e.g. advertising and agency expenses, travel costs, commissions, royalties, postal charges, insurance premiums, testing costs, consultancy fees, bank charges, contributions to chambers of trade and commerce and professional associations)?

[23]Although the quit rate function in equation 2 is linear in logs, estimating the equation in logs is not feasible because quits are zero in some establishment-years.

[24]Neglecting to account for heterogeneity may yield biased inference if wages are correlated with other determinants of the quit rate. For example, if non-wage amenities such as pleasantness of the job are reflected in compensating wage differentials, a naive estimate of γ that does not account for heterogeneity will be biased toward zero.

[25]The covariates included in the Mincer regression are a set occupation dummies, a set of education dummies, gender, nationality, age and age squared, a set of year fixed effects, federal state, and a set of sector dummies.

measure of the deviation of individual log wages from the market average. Averaging these residuals at the establishment-year level provides a log approximation to the term $\left(\frac{w-\overline{w}}{\overline{w}}\right)$ in equation (15).

To estimate equation (15), establishment-year quit rates minus the average quit rate were regressed on the average Mincer residuals, and a set of establishment and year fixed effects. The inclusion of establishment fixed effects identifies γ off of time series variation in wages within establishments, rather than cross-sectional variation in wages across establishments, which helps to account for the possible trade-off between wages and amenities. The estimated coefficient in regression equation (15) is -0.53, which corresponds to $-\overline{\delta}\gamma$. Dividing the estimated coefficient by $-\overline{\delta}$ yields an estimated γ of 5.75.

The average establishment-wide level of productivity, $\ln \bar{z}$, and the persistence, ψ_z, and variance, σ_z^2, of establishment-wide productivity shocks are estimated from the LIAB microdata using information on value added, VA_{it}, and the returns-to-scale parameter α calculated above. Using the measures of value added and the estimate of α described above, $\ln(VA_{it}) - \alpha \ln(n_{it})$ is regressed on a set of worker covariates, year fixed effects, and establishment fixed effects. The regression results allow for the calculation of annual establishment-level average productivity, a_{it}. Assuming the law of large numbers holds, the average level of u_{ijt} in the sample will be 1 each year, implying $z_{it} = a_{it}$. Regressing $\hat{a}_{it}$ on $\hat{a}_{i,t-1}$ and a set of establishment fixed effects yields estimates for the persistence of the establishment-level productivity process, ψ_z, and the variance of establishment-level productivity shocks, σ_z^2.

6.2 Estimated Parameters

The wage cut cost function parameters λ_0 and λ_2, the persistence and variance of shocks to worker-type productivity ψ_u and σ_u^2, and the hiring cost function parameters ϕ_1 and ϕ_2 are estimated through indirect inference to match a set of simulated moments from the theoretical model to their empirical counterparts in the data sample. For a given guess of these parameters, the establishment's optimal policy functions are computed and a series of wage change distributions and employment outcomes are simulated using a set of random shocks. Applying the same method of measuring establishment wage rigidity used in the empirical results to the simulated wage change distributions yields an estimate of wage rigidity for the establishment in the simulated data, $\hat{wr}^s$. For each guess of the wage rigidity parameters, the same procedure is implemented nine times, by multiplying the wage rigidity parameters by a multiplicative factor increasing linearly from zero to two, and the simulated measure of wage rigidity is calculated along with the simulated layoff, quit, and hire rates for each of the nine simulations. Regressing the simulated layoff, quit, and hire rates on $\hat{wr}^s$, as in equation 13 from section 5.1, yields the regression coefficients on wage rigid-

ity, $\hat{\beta}^s = \left[\hat{\beta}_\ell^{\ s} \quad \hat{\beta}_q^{\ s} \quad \hat{\beta}_h^{\ s}\right]'$, from the simulated data. Therefore, the indirect inference approach provides four natural targets to match from the data: $\hat{\beta}_\ell$, $\hat{\beta}_q$, $\hat{\beta}_h$, and $\hat{wr}$. Identifying the remaining model parameters requires additional moments from the data. These additional target moments are the predicted increase in the layoff rate associated with wage rigidity from the regression in column (1) of table III,[26] the average hire rate in the data sample, the average wage level, the standard deviation of wage changes for job stayers, and the magnitude of the average negative wage change in the data sample.[27]

While there is not a one-to-one correspondence between the target moments and the estimated parameters, λ_0 and λ_2 are identified primarily by the average level of measured wage rigidity $\hat{wr}$ and the magnitude of the average negative wage change in the sample. The empirically estimated level of wage rigidity reflects the total cost of wage cuts the establishment faces. Given the total cost of wage cuts, the average negative wage change identifies how much of the cost stems from the menu cost wage adjustment term, λ_0, and how much from the quadratic wage adjustment cost, λ_2. If the quadratic adjustment cost predominates, the establishment will be willing to cut wages by only a small amount and the magnitude of the average negative wage change will be small. If, however, the menu cost predominates, the establishment will exhibit few small negative wage changes and the negative wage changes the establishment does make will be large on average.

The worker-type productivity shock parameters ψ_u and σ_u^2 are identified mainly by the predicted increase in the establishment layoff rate associated with wage rigidity and the standard deviation of the average wage change. The hiring cost parameters ϕ_1 and ϕ_2 are identified mainly by the average hiring rate and average wage. Inclusion of the wage rigidity regression coefficients β_ℓ, β_q, and β_h, serves two purposes. First, the regression coefficients provide additional discipline on the estimated model parameters by ensuring that the relationships between wage rigidity and employment outcomes hold in the estimated model. Second, the regression coefficients help to correct for any possible model misspecification, in the sense that the regression coefficients are generated using the same procedure in the model as in the data.

With nine target moments from the data and six parameters to estimate, the model is over identified. The parameters are estimated by minimizing the sum of the squared percent deviations of the simulated moments from their empirical counterparts.[28] Table VII shows the empirical

[26] In other words, 0.029 times the average measured level of wage rigidity, 0.245, or 0.7 percent. This quantity is used as a target rather than the sample average layoff rate because the only source of layoffs in the model is wage rigidity. Presumably, there are additional causes of layoffs in the real economy.

[27] All of the simulated moments except for $\hat{\beta}^s$ are taken from the single simulation in which the multiplicative factor on the wage rigidity parameters equals one.

[28] More formally, let θ be a vector of the six structural parameters to be estimated and μ be a vector of the nine target moments. Let $\hat{\mu}^s(\theta)$ be the corresponding simulated moments for any guess of the parameters θ. Then the estimated structural parameters are

$$\hat{\theta} = \arg\min_{\theta} [\hat{\mu}^s(\theta) - \mu]' W^{-1} [\hat{\mu}^s(\theta) - \mu]$$

and simulated moments using the estimated parameters. The model generally matches the target moments well. In particular, the simulated level of estimated wage rigidity and the coefficients on estimated wage rigidity in the simulated layoff, quit, and hire regressions match the target moments closely. However, the simulated average wage is lower than in the data and the simulated average hire rate is higher than in the data. These two patterns are connected through the average wage's effect on the quit rate: lower wages generate higher quit rates, which in turn require the establishment to hire more workers to maintain its size.

Table VIII shows the estimated parameter values. The persistence and variance of worker-type productivity shocks are 0.622 and 0.648, respectively, implying that shocks to individual worker types are larger and more persistent than shocks to overall establishment productivity. The estimated hiring cost parameters, $\hat{\phi}_1$ and $\hat{\phi}_2$, require context to be useful. Applying the estimated values to the hiring cost function in equation 3 at the simulated average hire rate of 28.4 percent yields a per-employee hiring cost of 16.5 weeks of total compensation, higher than Muehlemann and Pfeifer's (2013) estimate of more than 8 weeks of wages for skilled German workers.[29] The positive estimate for ϕ_2 implies that there are diseconomies of scale in hiring, which is consistent with Muehlemann and Pfeifer.

The estimated wage cut cost parameters, $\hat{\lambda}_0$ and $\hat{\lambda}_2$, imply that the cost of the average-size simulated wage cut is 1,009 euros. Approximately 48 percent of the cost stems from the fixed cost λ_0 and approximately 52 percent stems from the quadratic adjustment cost λ_2. However, this calculation may make the quadratic cost of wage cuts parameter λ_2 appear less important than it truly is, as the establishment will moderate the size of the average wage cut in response to the quadratic cost. Applying the estimated menu and quadratic costs of nominal wage adjustment to the wage change distribution with no wage rigidity shown in figure III, 20 percent of the cost of an average-size simulated wage cut stems from the menu cost, while 80 percent stems from the quadratic cost. The importance of the quadratic adjustment cost relative to the menu cost may seem surprising, but it is worth recalling that the data used in the estimation pertain to total compensation rather than hourly or base pay, and thus are likely to feature more frequent small reductions than estimates derived from the latter sources.

6.3 Counterfactual Policy Simulation

The theoretical model can be used to conduct counterfactual policy simulations that examine the effects of changes in the structural parameters on economic outcomes. This section examines the effects of alternative deterministic inflation rates, holding all other model parameters constant,

where W is a nine by nine diagonal weighting matrix with the squared target moments as its entries.

[29] Muehlemann and Pfeifer's estimate applies only to skilled workers whereas the data in this paper covers all skill classes.

including the cost of nominal wage cut parameters λ_0, λ_1, and λ_2. Specifically, the simulations study an alternative low inflation rate of 0 percent and an alternative high inflation rate of 5 percent.

Figure XIV displays the simulated wage change distribution from the model with zero percent inflation. The asymmetry of this histogram is even more pronounced than in figure IV, and there is a large spike at the wage change bin containing a nominal wage change of zero. Furthermore, the distribution is even more compressed than in figure IV. The distinct effect of the menu cost of wage cuts is evident in the figure, as the proportion of nominal wage cuts less than 1 percent is noticeably lower than the proportion of wage cuts between 1 and 2 percent. Conditional on paying the menu cost, the quadratic adjustment cost discourages the establishment from instituting large nominal wage cuts. Figure XV displays the simulated wage change distribution from the model with 5 percent inflation. The median nominal wage change shifts noticeably to the right, consistent with a higher inflation rate. The distribution also becomes more symmetrical about the median and more dispersed, which is more reminiscent of figure III, which has no wage rigidity, than of figures IV and XIV. This change occurs because the higher inflation rate facilitates real wage cuts compared to the lower inflation cases. This effect is visually evident in the histogram, as all nominal wage changes less than 5 percent are real wage cuts.

Table IX shows the results of these simulations for employment outcomes, wage changes, revenues, and the resource costs of wage cuts. The simulated layoff rate declines from 0.5 percent in the case with 0 percent inflation to 0.1 percent in the case with 5 percent annual inflation.[30] The simulated quit rate rises from 24.0 percent to 25.2 percent when inflation increases from 0 to 5 percent and the simulated hire rate rises from 28.2 percent to 29.2 percent. The proportion of simulated wage changes that are real wage cuts likewise rises from 53.5 percent under 0 percent inflation to 62.0 percent under 5 percent inflation. The reduction in revenue relative to a case without any wage rigidity falls from 3.0 percent to 1.3 percent as inflation rises from 0 percent to 5 percent, while the resource cost of wage cuts as a proportion of revenues falls from 1.1 percent to 0.4 percent. These patterns are consistent with the idea that higher inflation facilitates real wage cuts in the presence of downward nominal wage rigidity, thereby mitigating its importance. The counterfactual policy simulations thus support the idea that inflation may "grease the wheels" of the labor market.

It should be emphasized, though, that there are two major obstacles to applying the results of these simulations to a welfare analysis of different target inflation rates. First, the model presented here has no mechanism for welfare costs from inflation; inflation's only role in the model is to reduce the importance of downward nominal wage rigidity. Second, the model is not a general equilibrium model. Embedding the model in a general equilibrium setting could change the results

[30] It is worth recalling that wage rigidity is the only source of layoffs in the model, which is why the simulated rates are smaller than the sample average layoff rate.

of the simulations in unpredictable ways, but is beyond the scope of this paper.

7 Conclusion

This paper explores the relationship between downward nominal wage rigidity and employment outcomes theoretically and empirically using German administrative data. A novel contribution of the paper is the use of linked establishment-employee data to measure wage rigidity and employment adjustment at the establishment level. Establishment-level wage rigidity estimates suggest a substantial amount of downward nominal wage rigidity in Germany, with an average of 24.5 percent of counterfactual wage cuts prevented by wage rigidity. The paper introduces a theoretical model of an establishment's wage and employment decisions in the face real resource cost for cutting nominal wages. The model predicts that more rigid wages should be associated with a higher layoff rate and lower quit and hire rates.

The empirical analysis is consistent with the predictions of the theoretical model. An establishment with the sample average level of measured wage rigidity is predicted to have a 0.7 percentage point higher layoff rate, a 1.8 percentage point lower quit rate, and a 1.3 percentage point lower hire rate than an establishment with no measured wage rigidity. The relationship between wage rigidity and employment outcomes is generally amplified by movements in establishment revenue. An establishment with the sample average level of wage rigidity and a one standard deviation decrease in revenue growth is predicted to have a 1.5 percentage point higher layoff rate relative to an establishment with no wage rigidity. An establishment with the sample average level of wage rigidity and a one standard deviation increase in revenue growth is predicted to have a 2.6 percentage point lower hire rate than an establishment with no wage rigidity.

Using the empirical results to estimate the structural model via indirect inference suggests that wage rigidity reduces the average establishment's revenues by 2.6 percent. The estimates imply that the average establishment faces a per-worker menu cost of 603 euros annually of cutting nominal wages. A counterfactual policy simulation suggests that inflation can "grease the wheels" of the labor market by facilitating real wage cuts even when nominal wage cuts are costly to achieve.

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Table I: Establishment-Level Descriptive Statistics

Number of Establishments	2,250
Sample Size, Establishment-Years	9,230
Mean Layoff Rate	0.045 (0.092)
Mean Quit Rate	0.092 (0.147)
Mean Hire Rate	0.172 (0.327)
Mean Employees per Establishment	549 (1,211)
Median Employees per Establishment	219
Mean Daily Wage, Nominal	102.395 (66.375)
Median Daily Wage, Nominal	90.500
Mean Daily Wage, Year 2000 Euros	101.813 (65.664)
Average Revenue Growth	0.035 (0.206)

Standard deviations in parentheses where applicable.

Table II: Establishment-Level Wage Rigidity Estimates

	Estimated Wage Rigidity		
	Mean	Median	Standard Deviation
All Establishments	0.245	0.218	0.235
Supersector:			
Agriculture	0.132	0.094	0.320
Mining/Manufacturing	0.128	0.104	0.217
Energy/Water	0.289	0.268	0.283
Construction	0.032	0.034	0.190
Trade/Foodservice	0.212	0.173	0.284
Transportation	0.115	0.104	0.234
Finance	0.311	0.303	0.222
Real Estate	0.216	0.151	0.340
Public Administration	0.459	0.490	0.270
Administration	0.355	0.398	0.306

Wage rigidity is estimated as discussed in section 4. The wage rigidity estimator is a fixed characterisitic of the establishment and estimates which fraction of nominal wage cuts were prevented due to downard nominal wage rigidity.

Table III: Wage Rigidity and Layoffs – Regression Results

Dependent Variable	Layoff Rate as a Fraction of Establishment Workforce		
	(1)	(2)	(3)
Wage Rigidity	0.029	0.029	0.025
	(0.005)	(0.005)	(0.006)
Positive Revenue Growth		0.005	0.012
		(0.005)	(0.007)
Negative Revenue Growth		-0.058	-0.015
		(0.010)	(0.014)
Wage Rigidity x Positive Revenue Growth			-0.038
			(0.024)
Wage Rigidity x Negative Revenue Growth			-0.193
			(0.044)
Work Council	-0.058	-0.052	-0.058
	(0.004)	(0.003)	(0.004)
R-squared	0.339	0.342	0.344
N	9,230	9,230	9,230

Standard errors in parentheses. Unit of observation is establishment-year. Layoffs are defined as a percentage of the establishment's total workforce on December 31 of the previous year. Wage rigidity is calculated as described in section 4 and is fixed by establishment over sample period. Each regression includes a set of etablishment characteristics, individual charactersistics, and year dummies as controls. Establishment characteristics include a set of controls for the median year-over-year wage change, occupational mix and dummies for sector, federal state, and establishment size. Individual characteristics include controls for gender and workers' education. Positive revenue growth is defined as the year-over-year percentage change in revenues when revenue growth is positive and zero otherwise. Negative revenue growth is defined as the year-over-year percentage change in revenues when revenue growth is negative and zero otherwise. All regressions require establishments to have at least 20 employees in a given year, are weighted by the square root of the number of employees, and cover the period 1997 to 2003.

Table IV: Wage Rigidity and Quits – Regression Results

Dependent Variable	Quit Rate as a Fraction of Establishment Workforce		
	(1)	(2)	(3)
Wage Rigidity	-0.072	-0.072	-0.056
	(0.008)	(0.008)	(0.009)
Positive Revenue Growth		0.037	0.079
		(0.008)	(0.012)
Negative Revenue Growth		-0.215	-0.225
		(0.015)	(0.022)
Wage Rigidity x Positive Revenue Growth			-0.192
			(0.038)
Wage Rigidity x Negative Revenue Growth			0.043
			(0.069)
Work Council	-0.047	-0.047	-0.047
	(0.006)	(0.006)	(0.006)
R-squared	0.341	0.355	0.357
N	9,230	9,230	9,230

Standard errors in parentheses. Unit of observation is establishment-year. Quits are defined as a percentage of the establishment's total workforce on December 31 of the previous year. Wage rigidity is calculated as described in section 4 and is fixed by establishment over sample period. Each regression includes a set of etablishment characteristics, individual charactersistics, and year dummies as controls. Establishment characteristics include a set of controls for the median year-over-year wage change, occupational mix and dummies for sector, federal state, and establishment size. Individual characteristics include controls for gender and workers' education. Positive revenue growth is defined as the year-over-year percentage change in revenues when revenue growth is positive and zero otherwise. Negative revenue growth is defined as the year-over-year percentage change in revenues when revenue growth is negative and zero otherwise. All regressions require establishments to have at least 20 employees in a given year, are weighted by the square root of the number of employees, and cover the period 1997 to 2003.

Table V: Wage Rigidity and Hires – Regression Results

Dependent Variable	Hire Rate as a Fraction of Establishment Workforce		
	(1)	(2)	(3)
Wage Rigidity	-0.053	-0.059	-0.053
	(0.015)	(0.014)	(0.015)
Positive Revenue Growth		0.048	0.103
		(0.014)	(0.019)
Negative Revenue Growth		0.025	0.106
		(0.025)	(0.036)
Wage Rigidity x Positive Revenue Growth			-0.261
			(0.064)
Wage Rigidity x Negative Revenue Growth			-0.362
			(0.116)
Work Council	-0.115	-0.115	-0.115
	(0.010)	(0.010)	(0.010)
R-squared	0.639	0.637	0.639
N	9,230	9,230	9,230

Standard errors in parentheses. Unit of observation is establishment-year. Hires are defined as a percentage of the establishment's total workforce on December 31 of the previous year. Wage rigidity is calculated as described in section 4 and is fixed by establishment over sample period. Each regression includes a set of etablishment characteristics, individual charactersistics, and year dummies as controls. Establishment characteristics include a set of controls for the median year-over-year wage change, occupational mix and dummies for sector, federal state, and establishment size. Individual characteristics include controls for gender and workers' education. Positive revenue growth is defined as the year-over-year percentage change in revenues when revenue growth is positive and zero otherwise. Negative revenue growth is defined as the year-over-year percentage change in revenues when revenue growth is negative and zero otherwise. All regressions require establishments to have at least 20 employees in a given year, are weighted by the square root of the number of employees, and cover the period 1997 to 2003.

Table VI: Calibrated Parameter Values

Parameter	Description	Value	Source
α	Returns to Scale in Production	0.650	Labor's Share of Value Added
$\overline{\delta}$	Average Quit Rate	0.092	Average Sample Quit Rate
$\overline{w}$	Average Daily Wage	103	Average Sample Wage
γ	Wage Elasticity of Quit Rate	5.75	Auxiliary Regression
$\ln \bar{z}$	Average Establishment-Wide Productivity	$4.03 \text{x} 10^5$	Auxiliary Regression
ψ_z	Persistence of Establishment-Wide Productivity	0.096	Auxiliary Regression
σ_z^2	Variance of Establishment-Wide Productivity Shock	0.325	Auxiliary Regression
c_l	Firing Cost	4,695	Redundancy Costs
$\bar{u}$	Worker Type Productivity	1	Normalization
π	Deterministic Inflation Rate	0.013	Average Inflation
β	Establishment Discount Rate	0.924	Real Interest Rate
λ_1	Linear Cost of Downward Wage Adjustment	0	Choice

The parameters for returns to scale in production, the average quit rate, the average daily wage, the wage elasticity of the quit rate, average establishment-wide productivity, the persistence of establishment-wide productivity, and the variance of the establishment-wide productivity shock are estimated through a series of empirical regressions and sample averages directly from the data, described in sections 3 and 6. The persistence of worker type productivity, the variance of the worker type productivity shock, the hiring cost parameters, and the nominal wage adjustment cost parameters are estimated by indirect inference as described in section 6. Firing costs are set to match German redundancy costs from the World Bank's Doing Business project, taking the average of the cost for workers with 1 year of tenure and workers with 5 years of tenure. The deterministic inflation rate is the average consumer price inflation rate from the World Bank's World Development Indicators. The real interest rate is the "lending interest rate" from the World Bank's World Development Indicators minus the calibrated inflation rate.

Table VII: Empirical and Simulated Moments

Moment	Sample Value	Simulated Value
Layoff Regression Coefficient on Wage Rigidity	0.029	0.028
Quit Regression Coefficient on Wage Rigidity	-0.072	-0.061
Hire Regression Coefficient on Wage Rigidity	-0.053	-0.055
Average Wage Rate	102.4	87.0
Standard Deviation of Percentage Wage Change	0.074	0.051
Measured Level of Wage rigidity	0.245	0.230
Predicted Increase in Layoff Rate Associated with Wage Rigidity	0.007	0.004
Average Hire Rate	0.172	0.284
Average Negative Wage Change	-0.042	-0.036

The coefficients on wage rigidity in the layoff, quit, and hire regressions are from column 1 of tables III, IV, and V, respectively. Measured level of wage rigidity is mean wage rigidity for all establishments from table II, calculated as described in section 4.

Table VIII: Estimated Parameter Values

Parameter	Description	Value
ψ_u	Persistence of Worker Type Productivity	0.622
σ_u^2	Variance of Worker Type Productivity Shock	0.648
ϕ_1	Linear Hiring Cost	23,689
ϕ_2	Quadratic Hiring Cost	59,025
λ_0	Menu Cost of Downward Wage Adjustment, Euros	603
λ_2	Quadratic Cost of Downward Wage Adjustment, Euros	$2.94\text{x}10^{-4}$

Parameters are estimated by the indirect inference procedure described in section 6.

Table IX: Counterfactual Simulated Outcomes with Alternative Inflation Rates

	Annual Inflation Rate (%)		
Outcome (%)	0.0	1.3 (Baseline)	5.0
Layoff Rate	0.5	0.4	0.1
Quit Rate	24.0	24.3	25.2
Hire Rate	28.2	28.4	29.2
Workers Receiving Real Wage Cuts	53.5	57.0	62.0
Revenue Reduction Relative to No Wage Rigidity	3.0	2.6	1.3
Resource Cost of Wage Cuts as Share of Revenue	1.1	0.9	0.4

The no wage rigidity case used for the revenue comparison uses the same parameters as in the base 1.3% inflation case except with the cost of wage cut parameters λ_0, λ_1, and λ_2 set to zero.

Figure I: Establishment Policy Functions with No Wage Rigidity

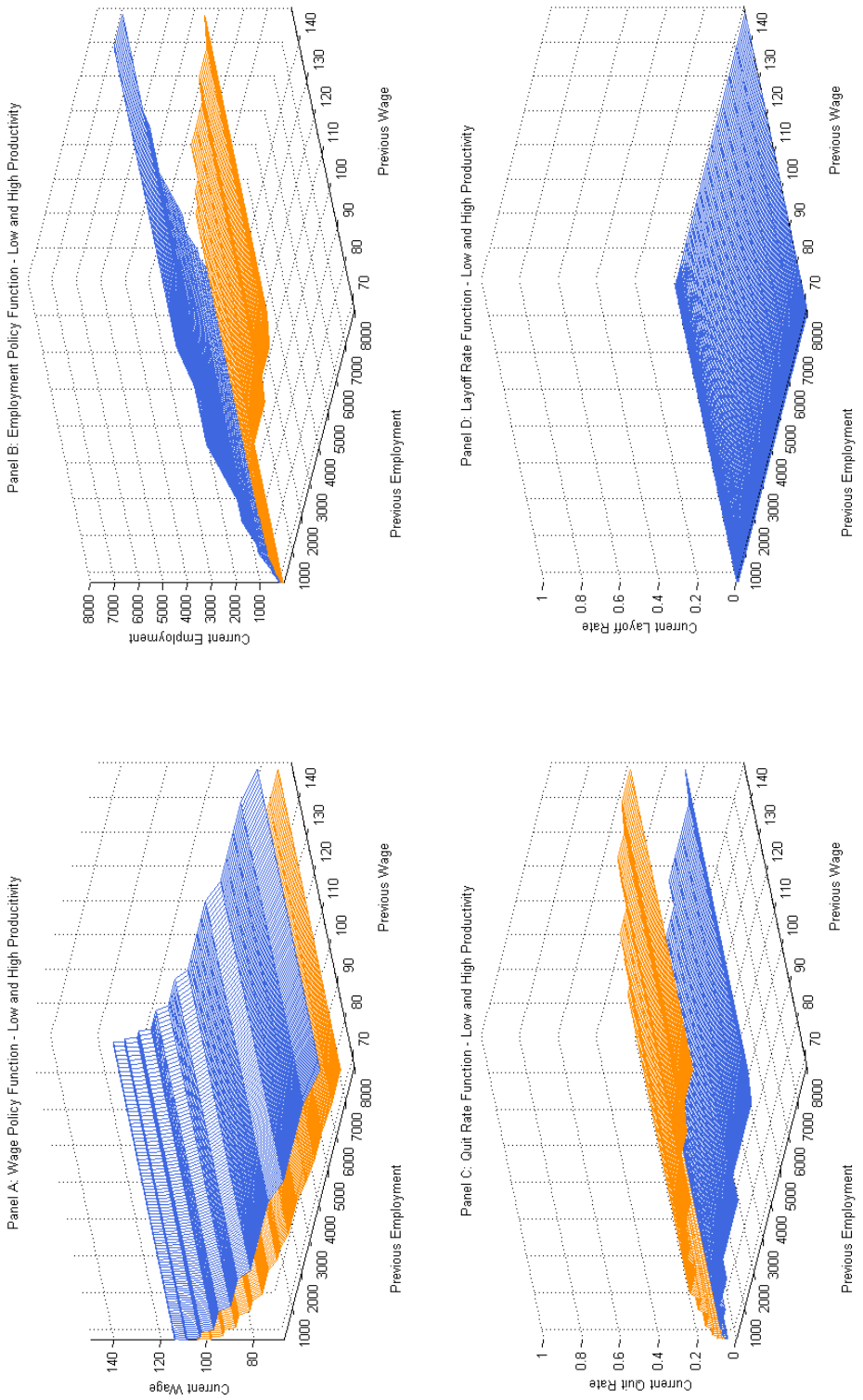


Figure II: Establishment Policy Functions with Wage Rigidity

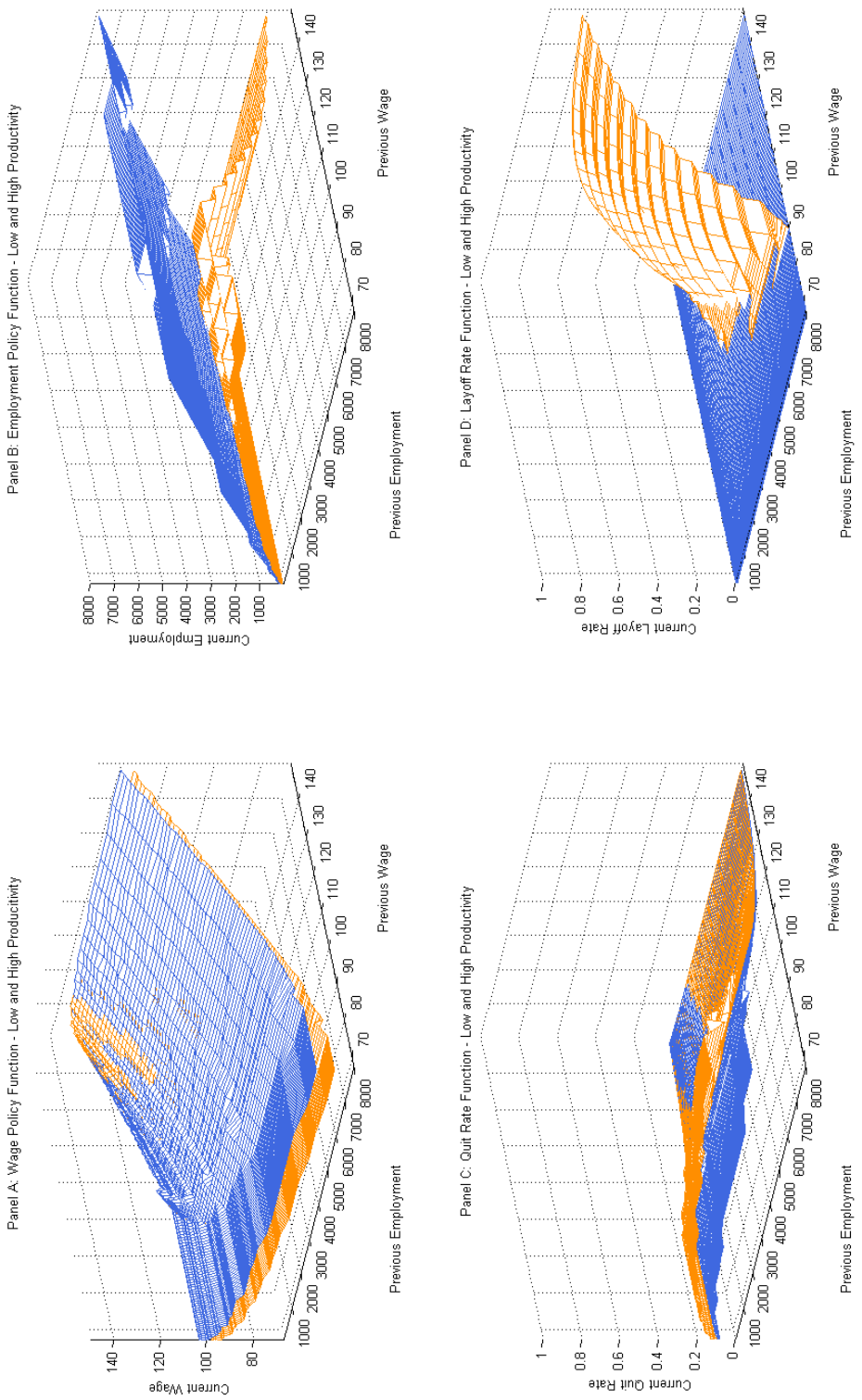


Figure III: Wage Change Distributions with No Wage Rigidity

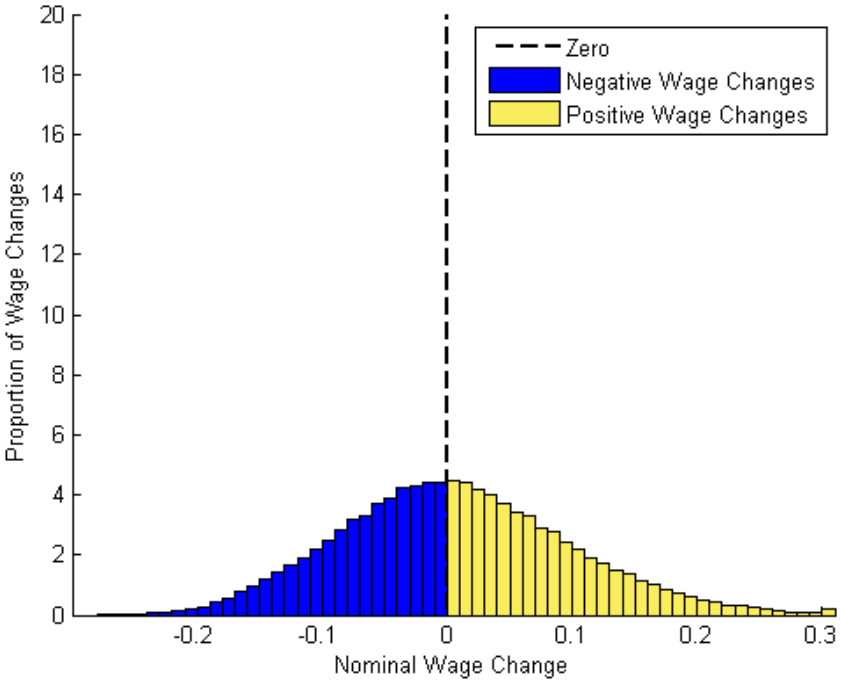


Figure IV: Wage Change Distributions with Wage Rigidity

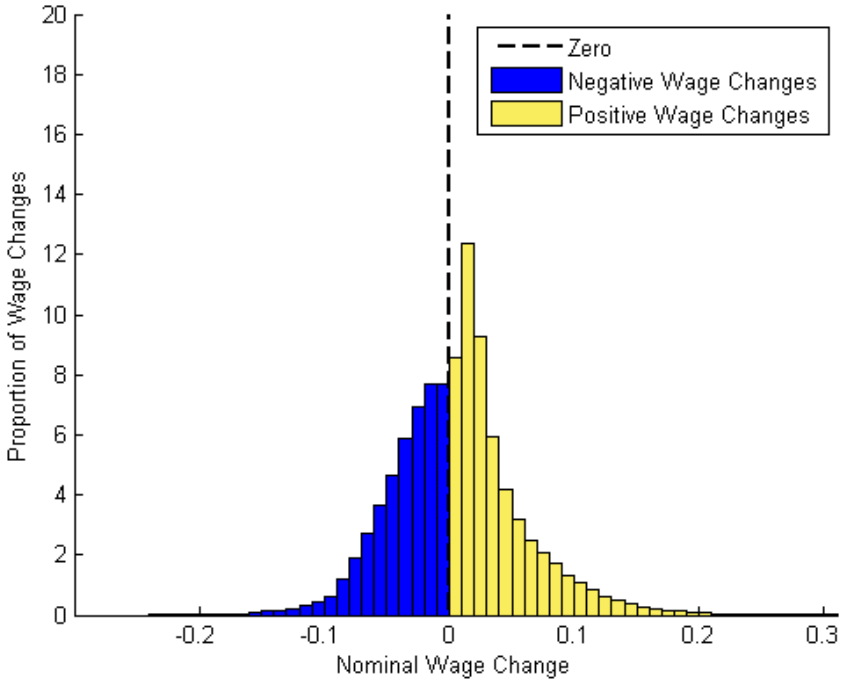


Figure V: Simulated Moments with Different Levels of Wage Rigidity

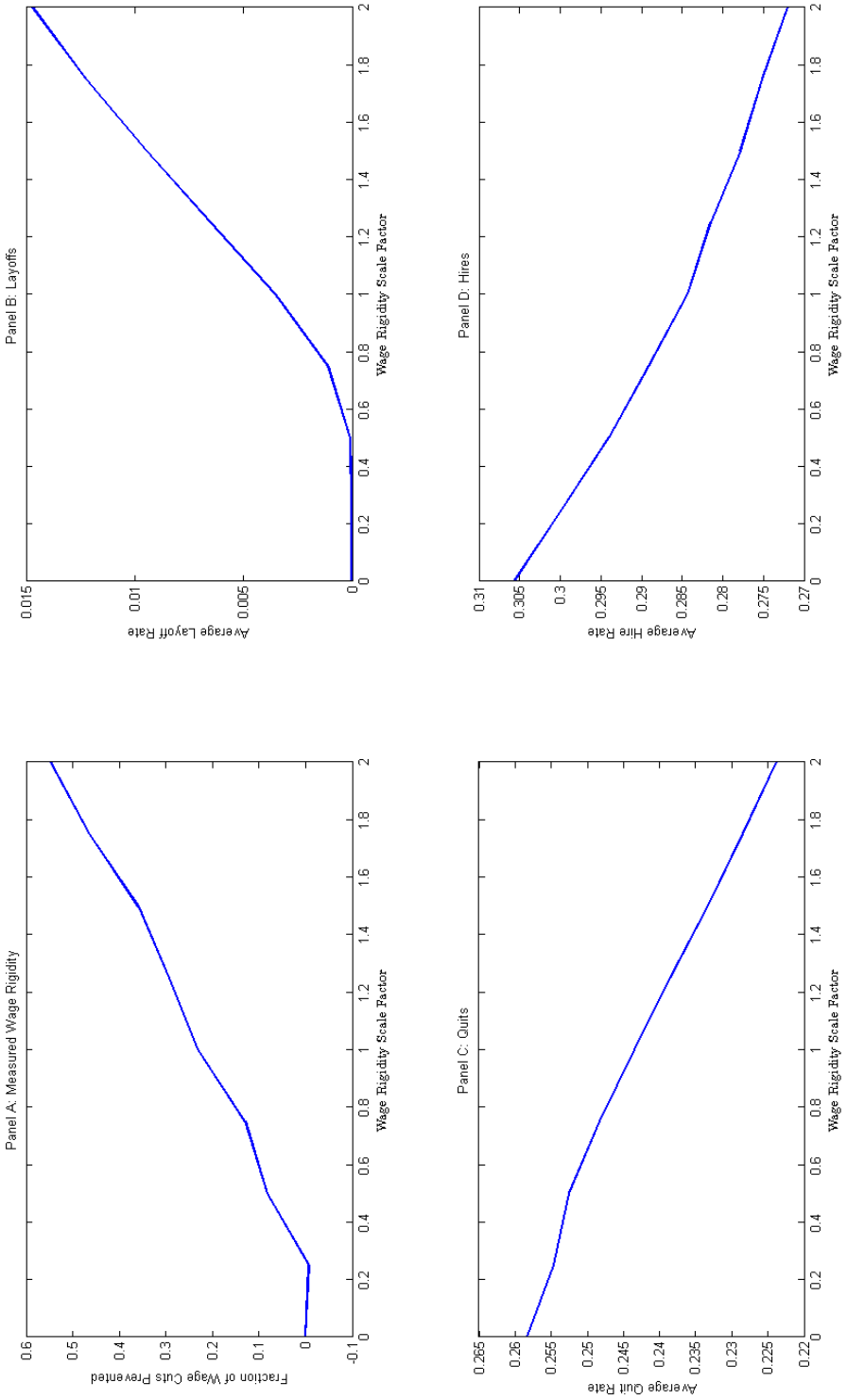


Figure VI: Aggregate Wage Change Distributions 1997 to 2003

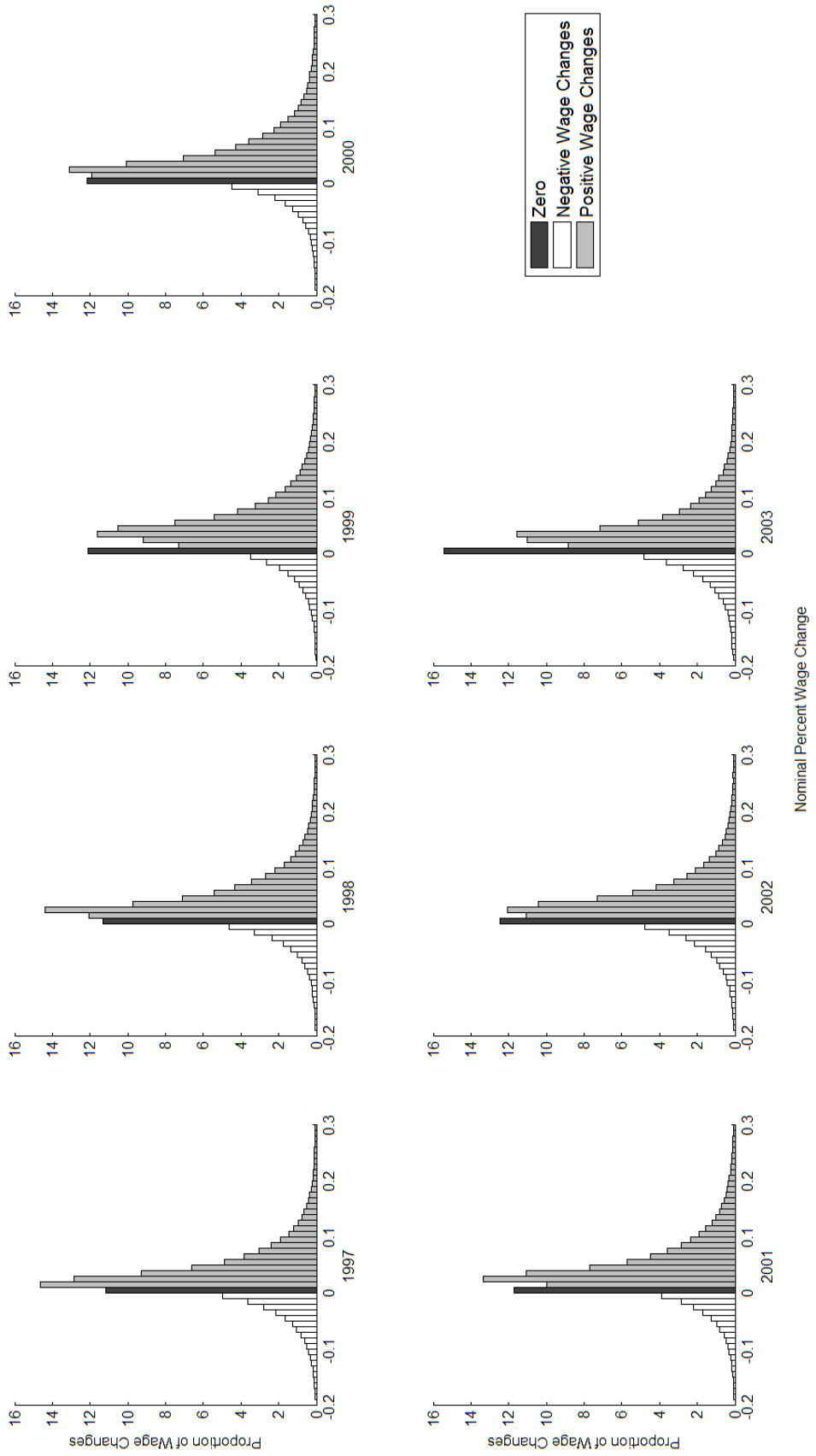


Figure VII: Illustration of Wage Rigidity Estimator

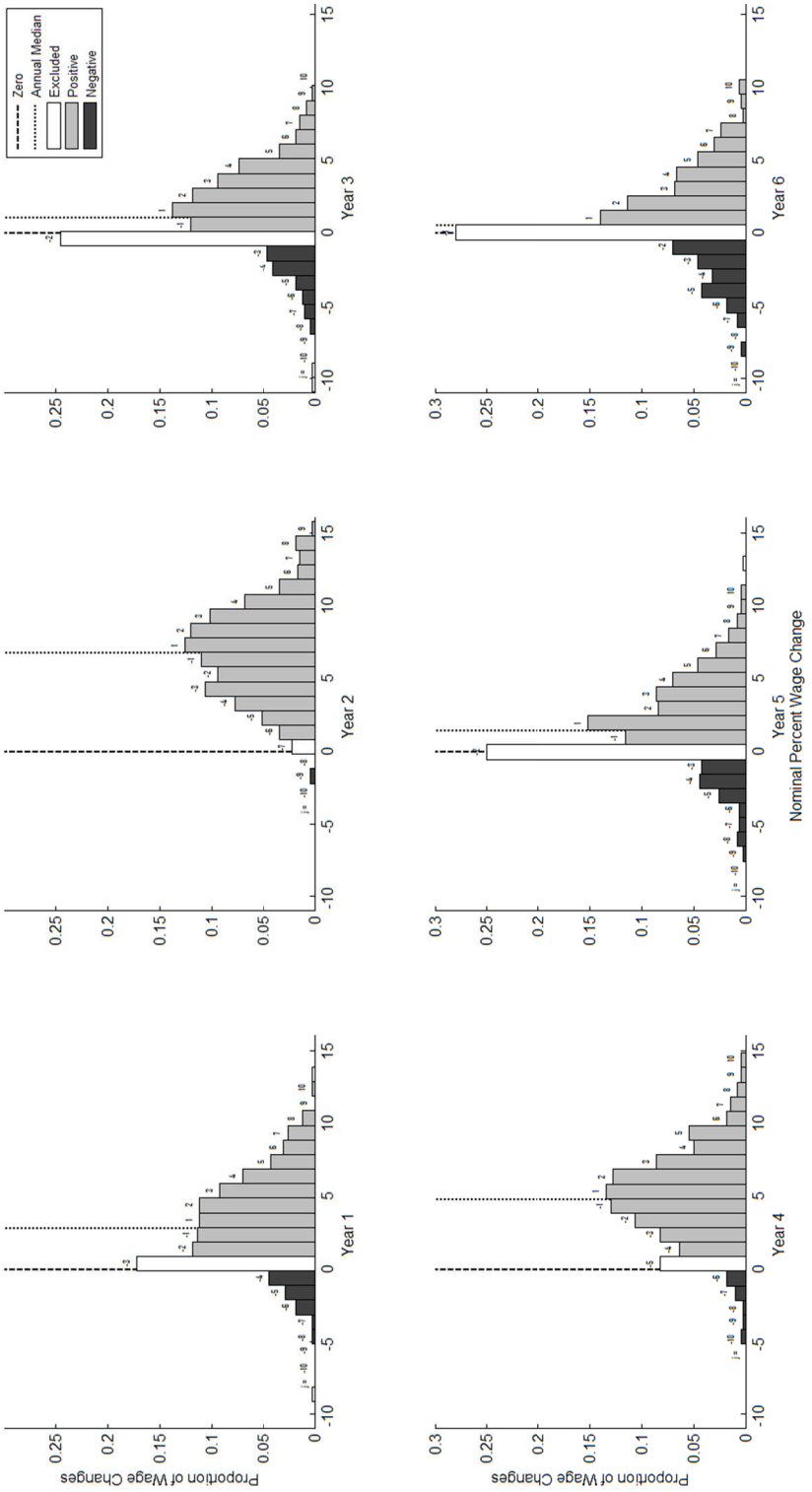


Figure VIII: Illustration of Wage Rigidity Estimator: Estimating Counterfactual Distribution

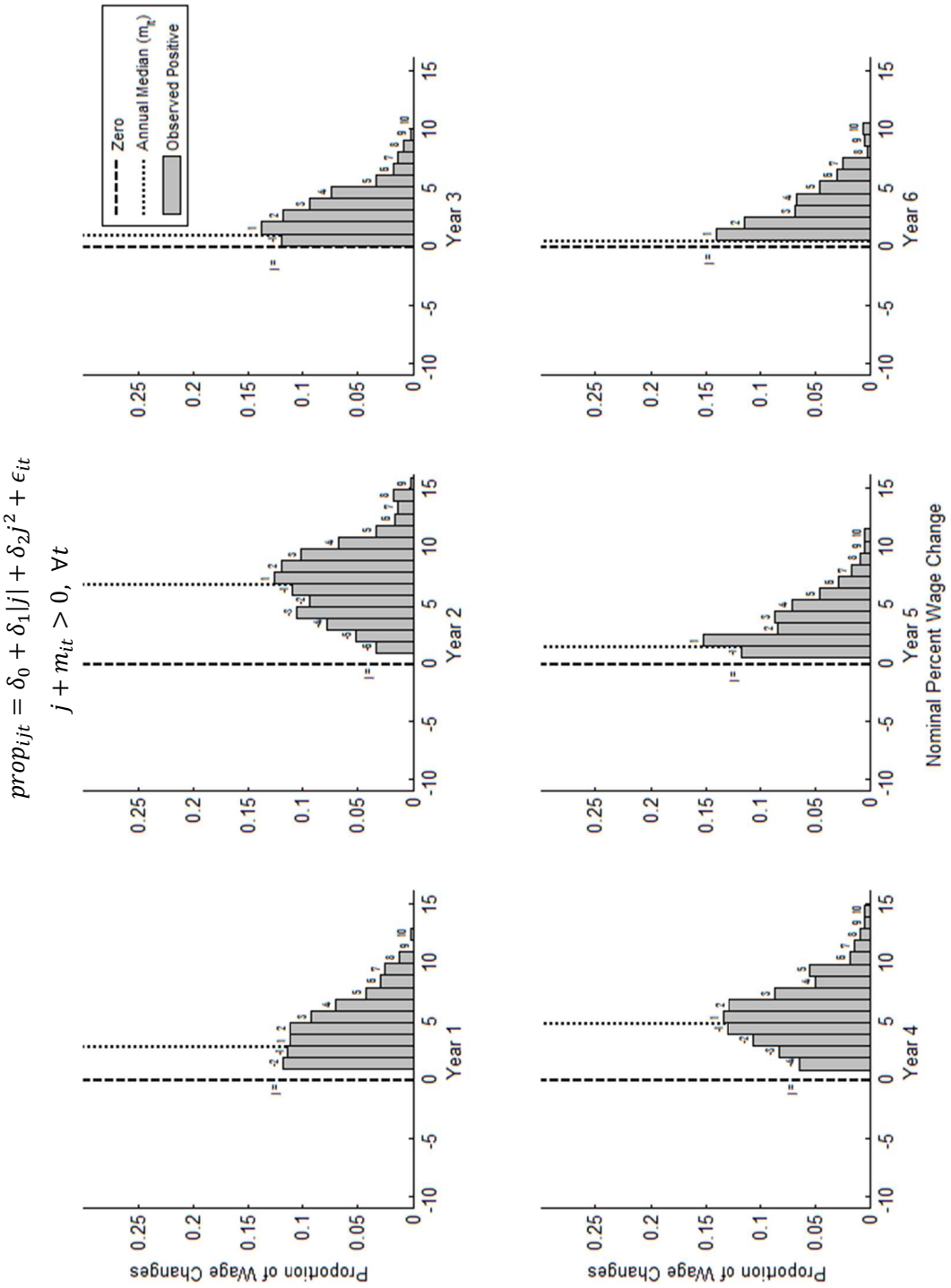


Figure IX: Illustration of Wage Rigidity Estimator: Counterfactual Negative Wage Changes

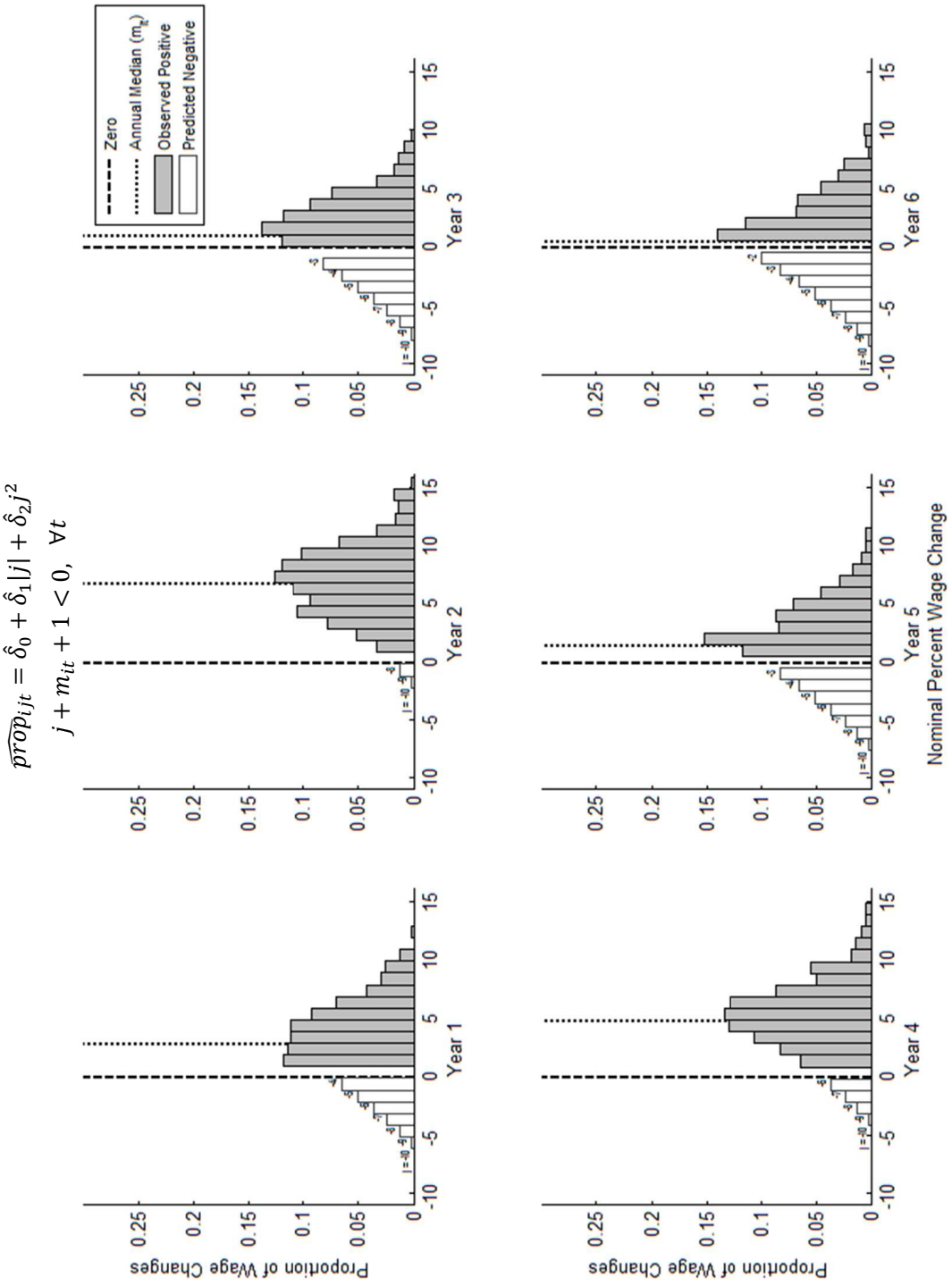


Figure X: Illustration of Wage Rigidity Estimator: Estimating Missing Wage Cuts

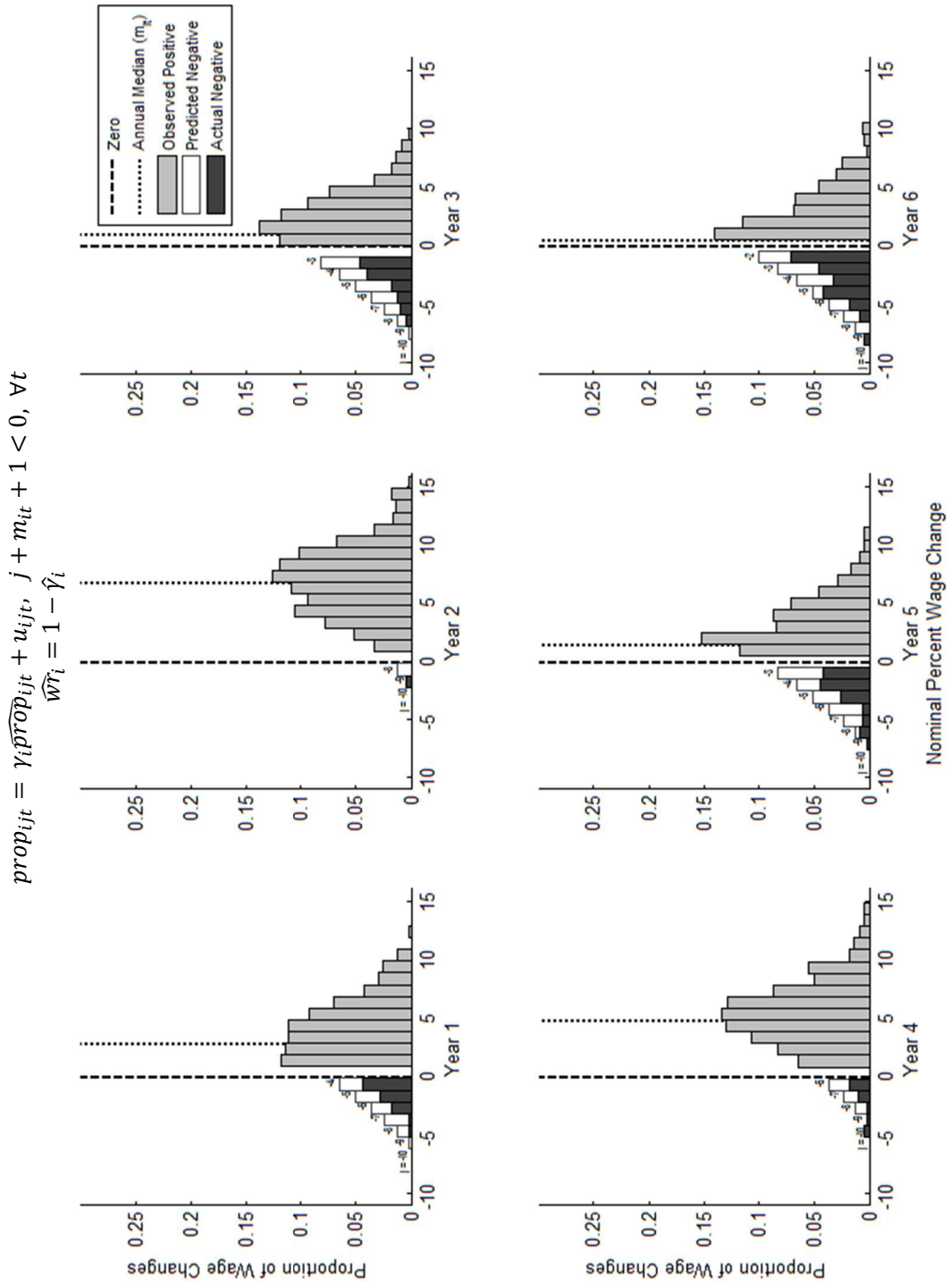


Figure XI: Layoff Regressions – Economic Significance

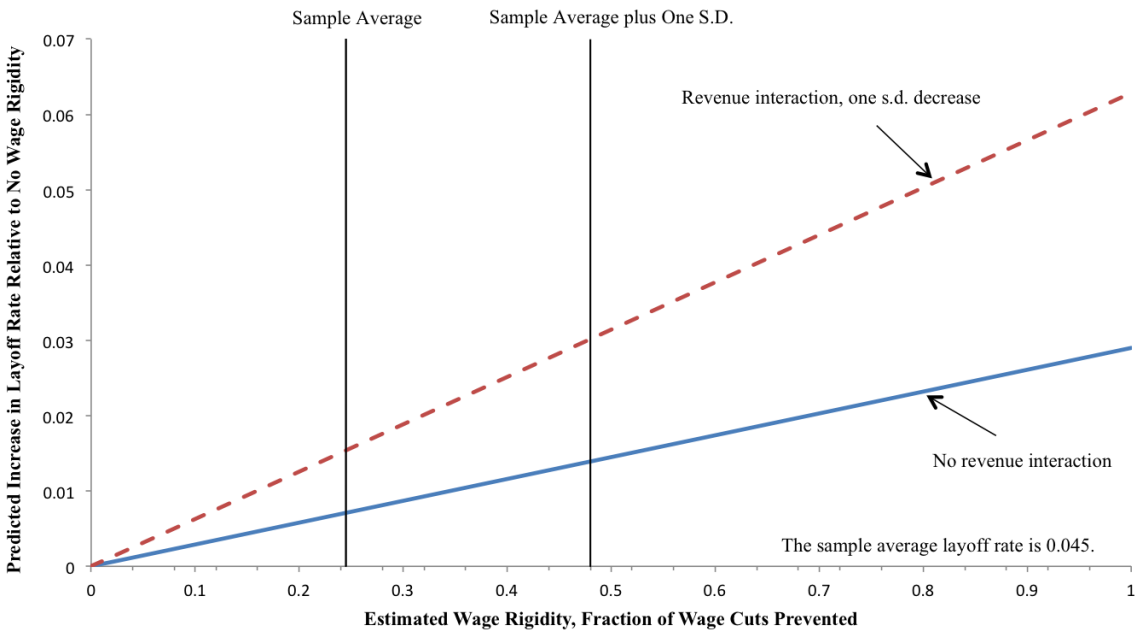


Figure XII: Quits Regressions – Economic Significance

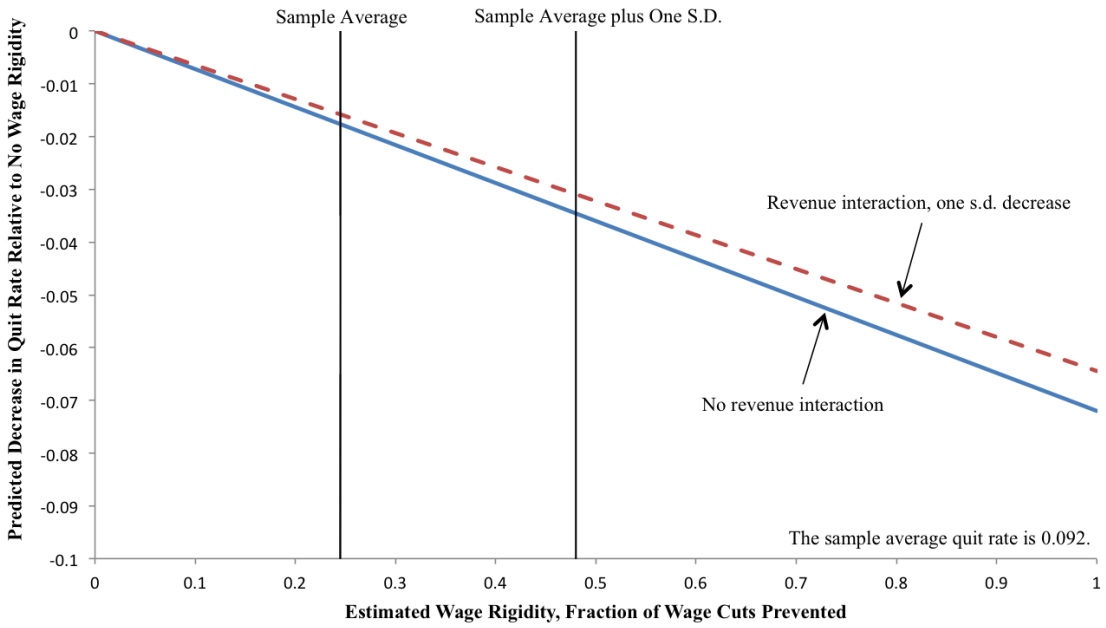


Figure XIII: Hires Regressions – Economic Significance

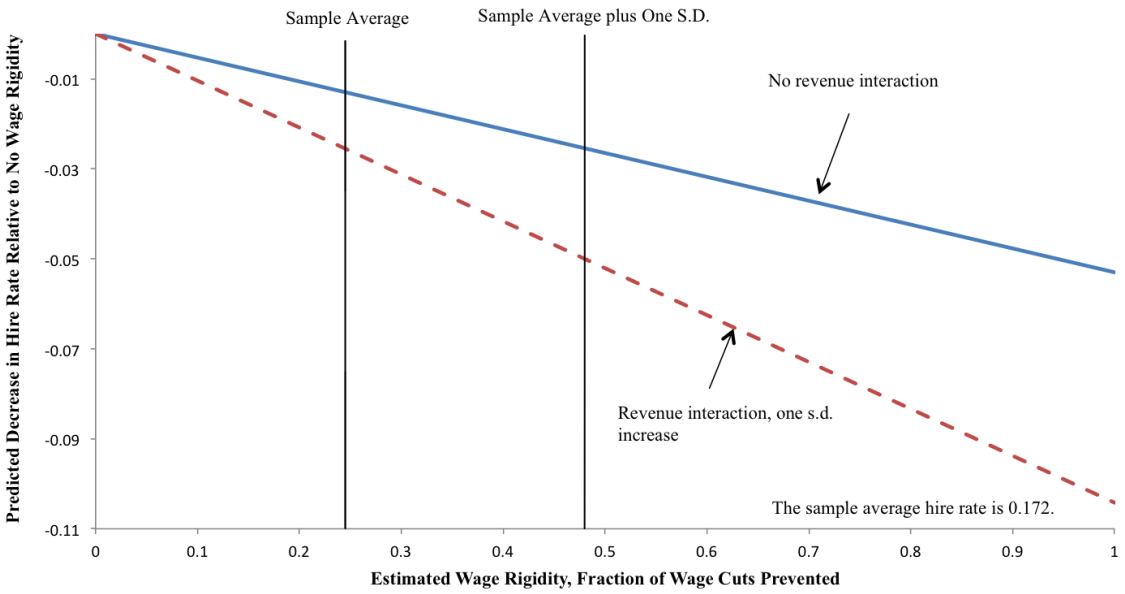


Figure XIV: Wage Change Distributions with Wage Rigidity and 0 Percent Inflation

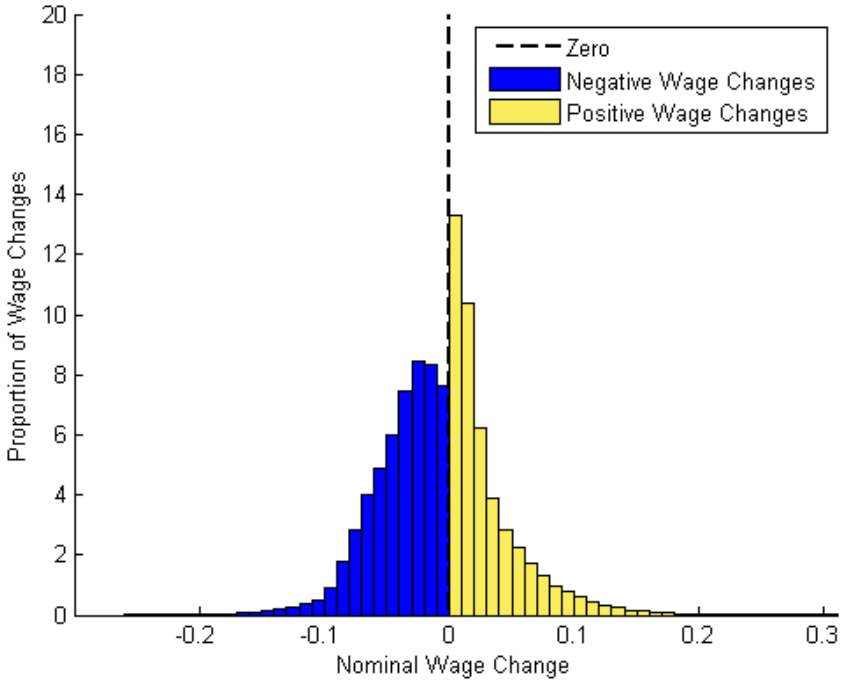
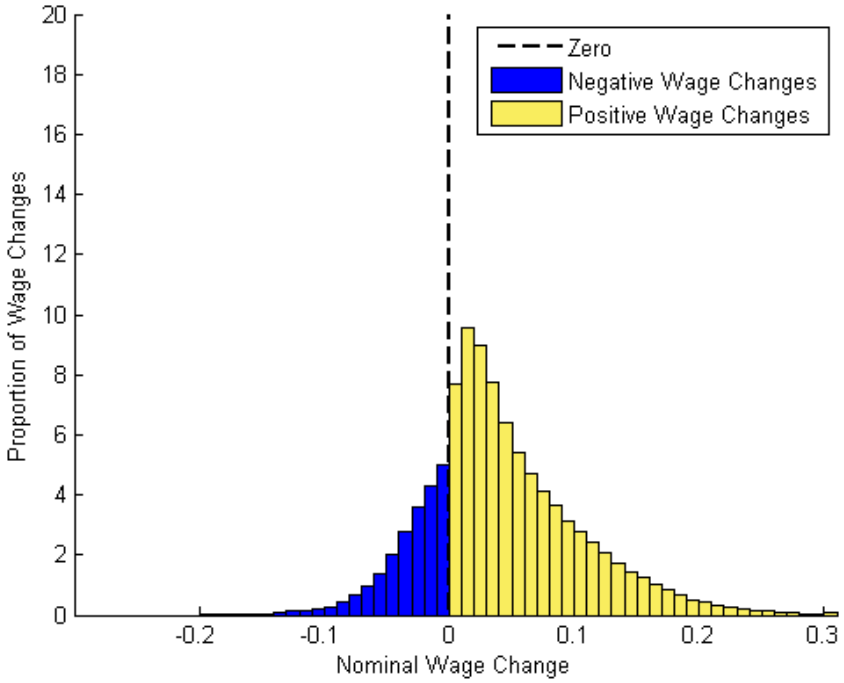


Figure XV: Wage Change Distributions with Wage Rigidity and 5 Percent Inflation



Appendix

A Monte Carlo Simulations of Wage Rigidity Estimator

This section tests the performance of the estimator of wage rigidity proposed in section 4 using Monte Carlo simulations. Wage change distributions for 500 establishments facing different levels of wage rigidity are simulated, with the number of years' worth of wage changes observed in the sample for each establishment generated as a random integer uniformly distributed between three and seven. Next, the number of employees per establishment is generated as a random integer uniformly distributed between 15 and 500; the number of employees is fixed over the simulation period. For each establishment the proportion of nominal wage cuts that will be prevented by downward nominal wage rigidity is also simulated as a random variable uniformly distributed over the interval [0, 1]: $wr_i \sim U[0, 1]$.

To simulate counterfactual nominally flexible wage change distributions for each establishment in each year, begin by drawing the mean of the establishment-year wage change distribution from a normal distribution with a mean of four percent and a standard deviation of four percent: $\mu_{it} \sim N(.04, .04^2)$. Then, draw the standard deviation of the counterfactual wage change distribution from a uniform distribution over the interval [0 .05] ($\sigma_{it} \sim U[0, .05]$) and draw the counterfactual flexible wage changes for each year from the normal distribution $\Delta \ln w_{ijt}^{cf} \sim N(\mu_{it}, \sigma_{it}^2)$, where $\Delta \ln w_{ijt}^{cf}$ is the counterfactual flexible log wage change of individual j at establishment i from year $t-1$ to year t.

Wage rigidity is introduced by replacing proportion wr_i of the counterfactual negative wage changes with positive wage changes that are distributed $N(.001, .005)$ to allow for prevented wage cuts to result in wage changes that are not exactly equal to zero. Wage cuts are chosen to replace randomly: there is no tendency for smaller wage cuts to be more likely to be prevented, for example. Finally, compression in the wage change distribution in the face of wage rigidity is introduced by multiplying counterfactual wage changes by a compression factor of $1 - 0.5wr_i$. That is, wage changes at an establishment with no wage rigidity will not be affected by wage compression, while wage changes at an establishment with 100 percent wage rigidity will be compressed by 50 percent. Introducing wage compression does not substantially change the simulation results.

The simulations use a reduced form method of simulating the wage change distributions in order to test whether the estimator of $\widehat{wr}_i$ provides unbiased estimates of the true wr_i in a setting in which a constant fraction of counterfactual wage cuts are prevented by wage rigidity. In contrast, there is not a direct correspondence in the theoretical model presented in section 2 between the cost of wage adjustment parameters λ_0, λ_1, and λ_2 and a fixed proportion of counterfactual wage cuts prevented.

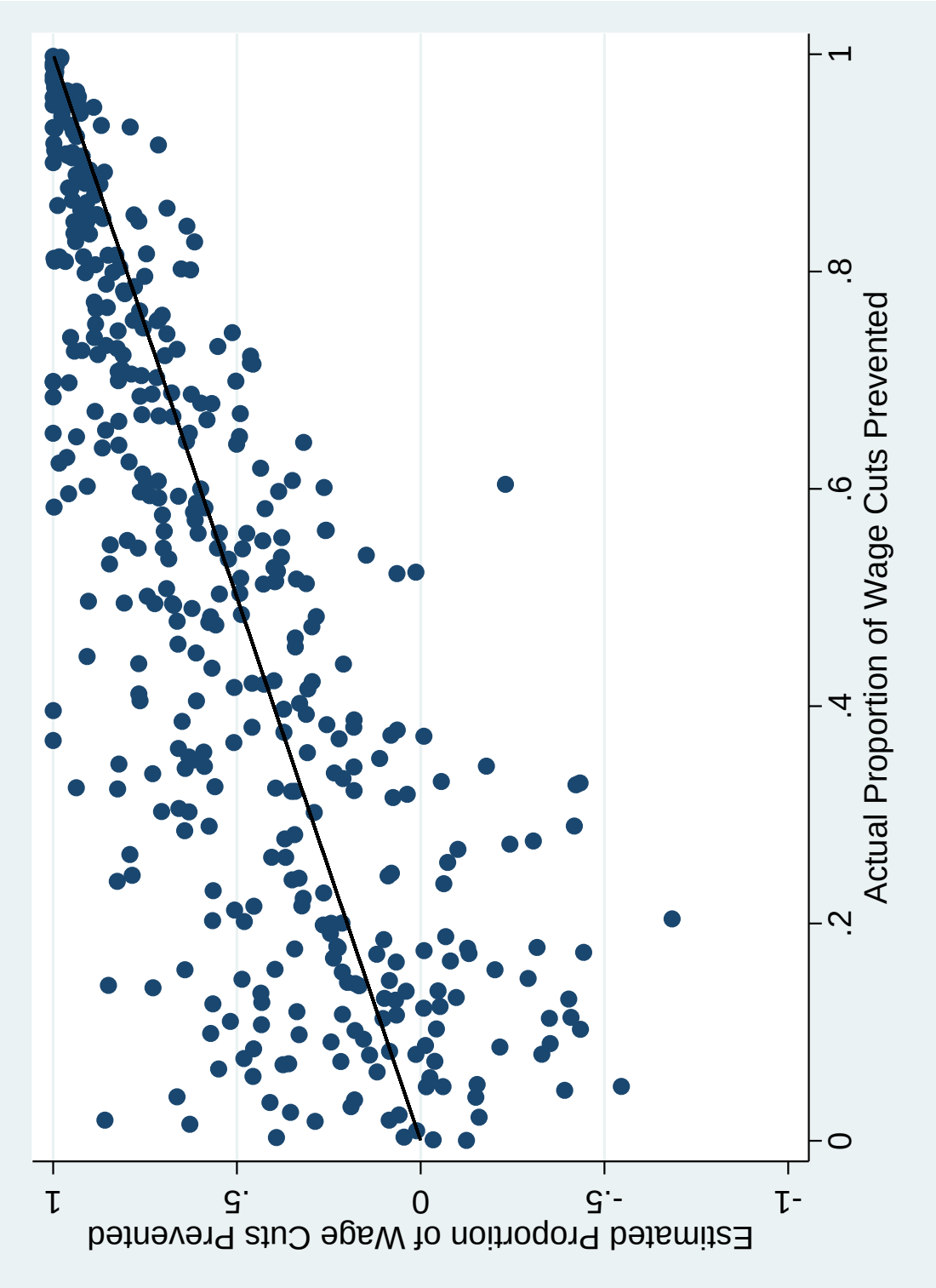
Figure A.I displays the estimated and actual proportions of counterfactual wage cuts prevented by wage rigidity in these simulations. A regression of the form

$$\widehat{wr}_i = \alpha + \beta wr_i + u_i \tag{A.1}$$

gives an estimate for $\hat{\alpha}$ of 0.036 with a standard error of 0.024 and an estimate for $\hat{\beta}$ of 0.982 with a standard error of 0.041. Therefore, $\hat{\alpha}$ and $\hat{\beta}$ are not statistically distinguishable from 0 and

1, respectively. These results imply that the proposed estimator of wage rigidity is likely to be unbiased in this context. The standard error of the regression is 0.24, nearly equal in magnitude to the standard deviation of the true amount of wage rigidity, which is 0.29. As discussed in the main text, this noise is likely to cause attenuation bias in the estimates of the relationship between wage rigidity and employment outcomes, meaning the true associations are likely to be larger than estimated in this paper.

Figure A.I: Monte Carlo Simulations of Wage Rigidity Estimates



B Aggregate German Wage Change Distributions, 1976-2005

This section displays the aggregate German wage change distributions from 1976 to 2005. The data is taken from the Sample of Integrated Labor Market Biographies (SIAB) described in section 3.1. The dataset contains a 2 percent random sample of workers liable to social security in West Germany during the sample period. The histograms display nominal percent wage changes for job stayers. The sample includes workers whose earnings are top-censored at the social security contribution limit; these workers are excluded from the histograms as their true wage is not known.

Figure B.I: Aggregate Wage Change Distributions 1976 to 1990

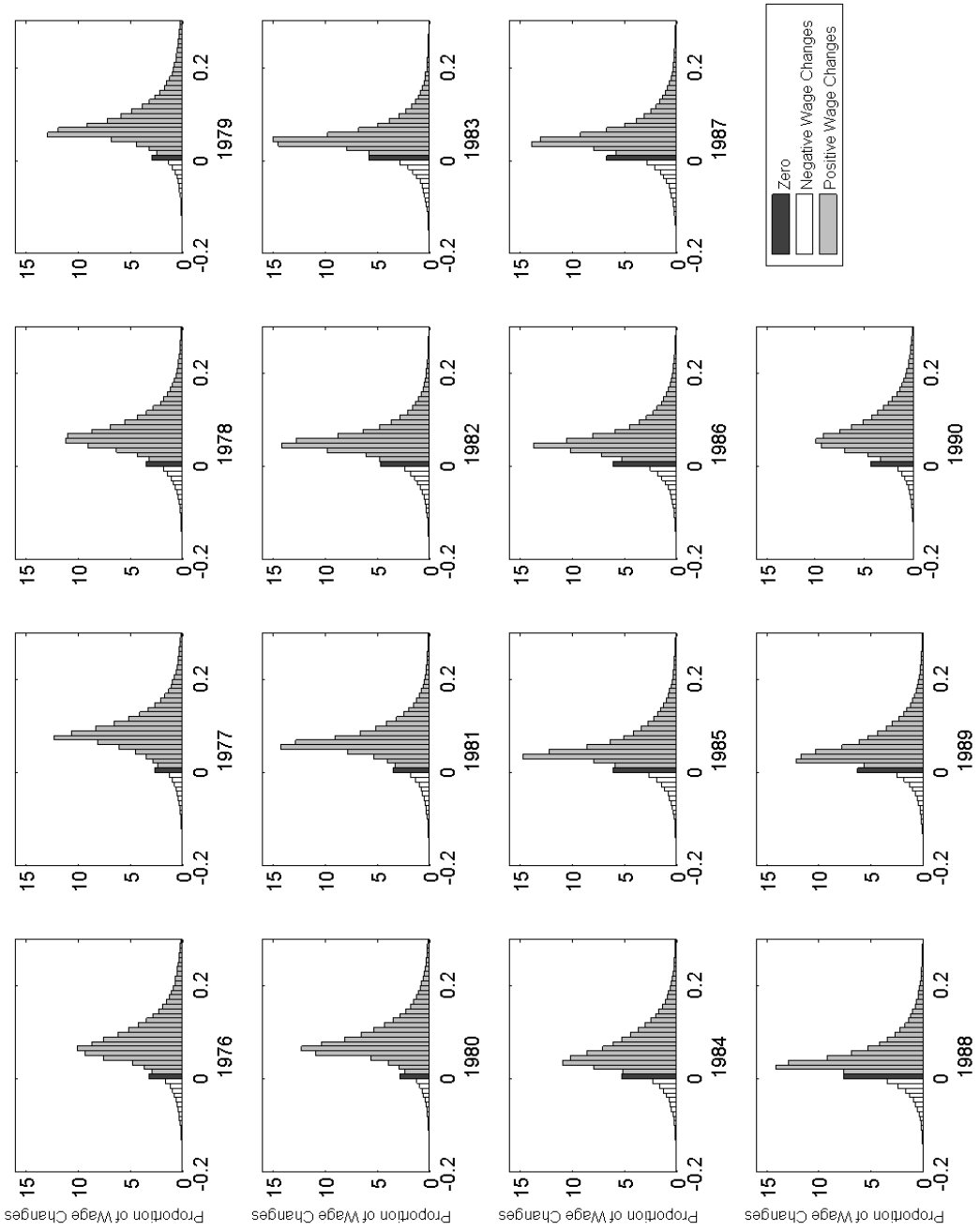


Figure B.II: Aggregate Wage Change Distributions 1991 to 2005

