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Firm Dynamics and the Minimum Wage: A Putty-Clay Approach

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PRELIMINARY

Abstract

We document two new facts about the market-level response to minimum wage hikes: firm exit and entry both rise. These results pose a puzzle: canonical models of firm dynamics predict that exit rises but that entry falls. We develop a model of firm dynamics based on putty-clay technology and show that it is consistent with the increase in both exit and entry. The putty-clay model is also consistent with the small short-run employment effects of minimum wage hikes commonly found in empirical work. However, unlike monopsony-based explanations for small short-run employment effects, the model implies that the efficiency consequences of minimum wages are potentially large.

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1 Introduction

One of the simplest predictions of economic theory is that an exogenous increase in wages results in a reduction in employment. The voluminous empirical literature testing this prediction using minimum wage hikes tends to find employment effects that are small (or even wrong-signed) relative to standard parameterizations of the theory. The implications of this finding for understanding how low-wage labor markets work and for the distortionary effects of minimum wages have been much debated.

Using administrative data from the ES-202 and the Census' Statistics of U.S. Businesses, we present new evidence on the effect of minimum wage hikes on establishment entry, exit, and employment among employers of low-wage labor. While many papers have studied the employment response to a minimum wage change (see e.g. Brown, Gilroy, and Kohen (1982), Card and Krueger (1995), and Neumark and Wascher (2008)), our study is among the first (see also Rohlin (2011)) to differentiate the employment of firms that exit or enter markets around the time of a minimum wage change with firms that are continuously active throughout this period. This decomposition provides clearer tests of models of low-wage labor market structure.

We find an increase in the minimum wage leads to an economically small and statistically mixed impact on short-run limited service restaurant employment. Notably, these results hold at detailed geographic data that allow us to match firms situated close to each other but separated by a state border (Dube, Lester, and Reich (2010) and Addison, Blackburn, and Cotti (2009)). But we show that this small net employment result hides a significant amount of churning. Increases in the minimum wage induce greater firm exit; in all three states that we study in the ES-202, firm exit rises by 4 to 7 percent in the two years after the minimum wage has been fully phased in relative to bordering states that did not experience a minimum wage change. The effects appear to be slightly larger as we move closer to the border. Similiar firm exit patterns are found in the more representative but more aggregated SUSB data. Models incorporating imperfect competition in labor markets, as in Bhaskar and To (1999) and Burdett and Mortensen (1998), can broadly reconcile these empirical findings.

More surprising, in both the ES-202 and the SUSB data, we find a simultanenous increase in firm entry. Indeed, the employment gains from entry are roughly matched by the losses

induced by exit, consistent with a small change in net employment in response to a minimum wage increase. Imperfect competition models do not predict such dynamics. Likewise, dynamic, stochastic competitive models like Hopenhayn (1992) do not predict a simultaneous short-run spike in both exit and entry. Moreover, employment must fall in competitive models like Hopenhayn's.

To capture the observed changes in entry, we extend the putty-clay models of Sorkin (2013) and Gourio (2011) to incorporate endogenous exit as in Campbell (1998). Firms can choose from a menu of capital-labor intensities when building an establishment, but once the establishment is built, output is Leontief between capital and labor. In this environment, adjusting the capital-labor mix in response to higher wages requires shutting down labor-intensive establishments and opening capital-intenstive establishments. Hence, this model is capable of predicting both entry and exit in response to a minimum wage hike.

Putty-clay technology generates two other predictions that appear consistent with findings in the minimum wage literature. First, the model implies that the cost of higher minimum wages are fully passed onto consumers in the form of higher prices (Aaronson (2001), Aaronson, French, and MacDonald (2008)). As Aaronson and French (2007) point out, the price pass through evidence is inconsistent with models of monopsony and efficiency wages, but is consistent with competitive models. Second, while the putty-clay model generates a small short-run employment response, the long-run disemployment response following a persistent minimum wage increase is notably larger. While the evidence on long-run effects is scarce, what little exists is consistent with this prediction (Baker, Benjamin, and Stanger (1999); Neumark and Wascher (2008)). In short, the putty-clay model can match the previously known facts on the employment and price responses to minimum wage hikes Sorkin (2013), as well as the new facts on short-run entry and exit presented in this paper.

2 Data

We use two data sources in this paper: establishment-level administrative data from the ES-202 and state-level data from the Census' Statistics on U.S. Businesses (SUSB). Each source has advantages. The ES-202 microdata is able to account more explicitly for geographic and

industry detail. The SUSB data is more comprehensive.

2.1 The ES-202

Under an agreement with the Bureau of Labor Statistics (BLS), we were granted access to the establishment-level employment data provided in the ES-202 data file. The ES-202 program compiles unemployment insurance payroll records collected by each state's employment office. The records contain the number of UI-covered employees on the 12th of each month.

We concentrate on three large minimum wage changes: a 17 percent increase in California phased in between January 2001 and January 2002, a 26 percent increase in Illinois phased in between January 2004 and January 2005, and a 39 percent increase in New Jersey phased in between October 2005 and October 2006. Table 1 provides details of the treatment and border control states we use. The three minimum wage states contain significant numbers of firms along state borders.

Like many studies before this one (e.g. Katz and Krueger (1992), Card and Krueger (1995), Card and Krueger (2000), Neumark and Wascher (2000), Aaronson and French (2007) and Aaronson, French, and MacDonald (2008)), we concentrate on fast food restaurants.[1] According to the Current Population Survey's Outgoing Rotation Groups, eating and drinking places (SIC 641) is the largest employer of workers at or near the minimum wage, accounting for roughly a fifth of such employees in 1994 and 1995 for example. Fast food establishments account for the majority of this share (Aaronson, French, and MacDonald (2008)).[2] Moreover, the intensity of use of minimum wage workers in the eating and drinking industry is amongst the highest of the industrial sectors.[3] For example, 23% of all restaurant industry workers are paid within 10% of the minimum wage (Aaronson and French (2007)).

The data, like most administrative databases, is rich in some ways but lacking in others. On the positive side, it encompasses the full population of firms and these businesses can be

[1] Unfortunately, prior to 2001, industry codes were unable to differentiate fast food, or more precisely limited service, and full service outlets. This is one reason why we concentrate on minimum wage changes in the 2000s. Another reason is that there is significant concern about the accuracy of single establishment reporting prior to 2001. We describe this problem below.

[2] The next largest employer, retail grocery stores, employs less than 7 percent of minimum or near minimum wage workers.

[3] In "limited service" (LS) outlets, meals are served for on or off premises consumption and patrons typically place orders and pay at the counter before they eat. In "full service" (FS) outlets, wait-service is provided, food is sold primarily for on-premises consumption, orders are taken while patrons are seated at a table, booth or counter, and patrons typically pay after eating.

followed for long stretches of time. This is particularly important for describing longer-term decisions like exit and entry. The main downside to the data is a paucity of information that do not directly touch on its purpose, which is a payroll count.

We append one important measure to the files: driving time and distance measures downloaded and calculated from Mapquest.com and maps.yahoo.com. These are computed using the ES-202's zip code identifiers. We use these travel distances to calculate a measure of across-state competition for firm i in state s by finding and aggregating all firms not in state s that are within d miles of firm s. For distance d, we use 15, 25, and 50 miles. Our distance estimator, which can be thought of as a propensity score, is ultimately a weighted comparison of establishments based on proximity.

There are two data issues with regard to creating a consistent panel of firm employment. First, for the early years (prior to 2001), we must rely on retroactive NAICS codes assigned by the BLS. This impacts the California estimate in particular. In this case, when the establishment cannot be mechanically traced back in time, our imputation relies on an establishment's nearest neighbor in employment space within the same state. Of course, not all establishments are coded and there is a clear bias in non-coding towards those that attrit from the sample. As much as the minimum wage causes exit, this introduces a potential bias into estimates based on samples that use these codes. Nevertheless, most of our results are based on results that take advantage of the much larger samples that can be observed using NAICS codes. The other two state minimum wage hikes that we describe take place after 2000 and therefore we develop the sample based directly on NAICS codes. Since actual changes in the NAICS codes are indistinguishable from NAICS code corrections, we require establishments to have a code of 722211 in either the final period or the final period in which the establishment appears.

Finally, we make one important sample restriction that eliminates a small fraction of establishments. We only include establishments with employment between 1 and 100 in the starting period, which we define as two years prior to the minimum wage change. The upper bound restriction is to deal with an important institutional feature of the ES-202. Particularly earlier in our sample period, the BLS encouraged multi-unit establishments to report their figures at the county-level. As much as our analysis is done at the county-level, this might not

appear to matter. However, over time, the reporting of multi-establishments often changes. Consequently some establishments can be lost simply by changes to the store identifiers. The 100 employee bound is meant to isolate obvious cases of multi-establishment reporting. Card and Krueger (2000) also experiment with the robustness of their results to including upper bound employment counts, with little inferential consequences. Moreover, there is a supplemental ES-202 dataset called the Business Employment Dynamics (BED) which allows one to link establishments that have changed their reporting mode. While the BED proved to be an unreliable means for imputing employment levels at the lowest level of aggregation, it allowed us to identify establishments that were involved in a change in reporting mode. Without being able to reliably link establishments and impute employment levels, these changes will appear to be entries and exits, and since such establishments represent less than 2% of the dataset we chose to drop them.

2.2 The Statistics of U.S. Businesses (SUSB)

Our second dataset is the Census Bureau's Statistics of U.S. Businesses, a state-level panel derived from the Business Registry and various economic Census surveys of births, deaths, contractions, and expansions for all non-agricultural U.S. business establishments with paid employees from 1998 to 2008.[4] We focus on establishments with fewer than 20 employees in the accommodation and food service industry (NAICS 72), the most disaggregated data available for the restaurant sector. We also discuss estimates for establishments up to 99 employees, similar to the restriction we placed on the ES-202 data. However, because the SUSB industry disaggregation is not as fine as the ES-202, we prefer the smaller firm size threshold.

The SUSB contains four main outcome variables: the number of establishments that are born, die, contract employment, and expand employment. A birth (death) is an establishment with no (positive) employment in the first quarter of the year and positive (no) employment in the first quarter of the subsequent year. Establishments with positive employment in both quarters but are growing (contracting) are counted as expansions (contractions). All variables are normalized by the number of establishments at the beginning of the year. A

[4]Data prior to 1998 is disaggregated to only the one-digit SIC code (e.g. retail trade) and therefore we do not use it.

second set of four outcomes are based on employment changes arising from births, deaths, contractions, and expansions. For these variables, we normalize by the count of employment at the beginning of the year.

When state-year cell sizes are small enough to potentially identify firms, the Census will not release those data. This issue impacts a small number of state-years for employment but not establishment counts. Furthermore, we exclude years when the state minimum wage was automatically adjusted for changes in the Consumer Price Index[5]. These restrictions leave 525 state-year observations for outcomes related to establishment counts and between 504 and 525 observations for outcomes related to employment.

Summary statistics are available in appendix Table A1.

3 Empirical Strategy

Our empirical estimates are based on the statistical model:

$$Y_{st} = \sum_{j=0}^{1} \beta_j w_{st-j} + a_s + a_t + \epsilon_{st} \tag{1}$$

where Y_{st} is an outcome of interest during time t (in years) in state s, w_{st-j} is the minimum wage in state s at time $t-j$, and a_s and a_t are state and time indicators. $\{\beta_0, \beta_1\}$ are the key parameters to be estimated. We include a lag in the minimum wage to allow some delay in the entry and exit response.

While our SUSB-based results come directly from panel estimation of equation (1), the ES-202-results are derived from the experiences of three states – California, Illinois, and New Jersey – and their adjacent neighbors in the early to mid 2000s. The three minimum wage hikes we evaluate are enacted in two steps, 1 year apart. To address this, we consider changes in Y_{st} between 1 year before the first state level hike to 1 year after the second state level minimum wage hike. Defining t^1 as the time of the first minimum wage hike in state s and ς as the comparison state, we calculate the difference-in-difference estimator $(Y_{st^1+2} - Y_{st^1-1}) - (Y_{\varsigma t^1+2} - Y_{\varsigma t^1-1})$, which we show in Appendix D equals $\sum_{j=0}^{1} \hat{\beta}_j (w_{st^1+1} - w_{st^1-1})$.

[5]Through 2008, states with legislation that automatically adjusted the minimum wage level for changes to the CPI are Arizona (starting in 2008), Colorado (2008), Florida (2006), Missouri (2008), Nevada (2006), Ohio (2008), Oregon (2004), Vermont (2007), and Washington (2001).

The outcomes Y_{st} are employment, entry, and exit rates. For the SUSB data, we measure entry rates as $(entrant_{st})/e_{st-1}$, where $entrant_{st}$ is the number of firms that did not exist at time $t-1$ but did exist at time t and e_{st-1} is the number of firms in existence at time $t-1$. Similarly, the exit rate is $(exit_{st})/e_{st-1}$, where $exit_{st}$ is the number of firms that did not exist at time t but did exist at time $t-1$. When estimating entry and exit in the ES-202 data, we measure entry as $entrant_{ist}$, which is an establishment level indicator for whether establishment i existed at time t and not at time $t-1$, and $exit_{ist}$ as an indicator variable for whether establishment i existed at time $t-1$ and not time t. Appendix D demonstrates that these definitions of entry and exit are the exact establishment-level counterpart to our state-level SUSB definitions.

A key advantage of the ES-202, relative to the SUSB, is the detail of the establishment's geographic location. State-level regressions like equation (1) may confound the impact of the minimum wage with the economic conditions that allowed minimum wage legislation to move forward. The geographic detail in the ES-202 allows us to consider comparisons of close-by restaurants that likely confront similar economic environments but lie across state borders and therefore face different minimum wage requirements. To this end, we report three sets of estimates for each state level minimum wage hike. The first compares establishments in counties that physically border the comparison state, what we refer to as border counties (e.g. Dube, Lester, and Reich (2010)). Second, we look at the remainder of firms, that is those that are not in counties that border state boundaries, or what we refer to as interior counties. The "interior" limited service food establishments typically do not compete directly with analogous establishments in other states that face lower marginal costs due to the minimum wage.

Finally, this simple county border categorization is rather crude in the way it assumes shocks vary over distance. Therefore, our third set of estimates are based on a matching estimator that compares driving distance between zip codes near state borders, as computed by mapquest.com. These distance estimators compare competitor firms in close proximity (25 or 50 miles). That is we are careful to match limited service establishments in, say, Northeast Illinois with limited service establishments in Northwest Indiana. This approach follows the work of McMillen and McDonald (2002) and others, who use locally weighted

regression or propensity scores to match geographic areas, and is ultimately an offshoot of the linear locally weighted matching estimators of Heckman, Ichimura, and Todd (1997).

4 Results

4.1 ES-202

4.1.1 Net Employment

The first row in table 2 shows results for net employment for the three state experiments, reported separately by interior counties (column 1), state border counties (column 2), and establishments within 50 or 25 miles of a competitor from another state (columns 3 and 4). Rows 2 and 3 in each panel report the minimum wage elasticity and overall wage elasticity. The latter assumes that 40 percent of limited service establishment workers are impacted by the minimum wage (Aaronson and French (2007)).

Across all three states, we find little evidence of an economically notable net employment response to a minimum wage change. Net employment appears to have fallen in California following the 2001/02 increase, but the effects are small and sometimes indistinguishable from zero. The employment effects following the large minimum wage changes in Illinois and New Jersey are likewise small and indistinguishable from zero. These results appear to be similar to recent studies (Dube, Lester, and Reich (2010); Addison, Blackburn, and Cotti (2009)) that use alternative county-level datasets to explore net employment adjustments along state borders.

4.1.2 Employment among continuously active firms

Table 3 provides the same estimates for firms that are continuously open throughout the treatment period. Here, again, we find little evidence of a consistent net employment effect. Employment falls along the New Jersey border but the effect is small and not consistent with the near zero effects in California or Illinois. Interestingly, employment grows slightly in the interior counties of all three minimum wage states, with minimum wage elasticities that range from 0.02 to 0.04.

4.1.3 Firm Exit and Entry

Although net employment barely budges, table 4 highlights that a significant amount of additional firm churning occurs around minimum wage changes. The first row of each panel shows the impact of a minimum wage on firm exit two years after the initial hike. Across states, the results are fairly similar; exit rates are roughly 4 to 7 percentage points higher than they would be absent such an increase. This result is particularly strong in New Jersey and California and a bit more mixed in Illinois as we get closer to the border. Generally, the numbers are economically large relative to the baseline population. For example, the 7 percentange point increase in exits along the New Jersey border corresponds to roughly 125 additional establishments in New Jersey border counties. At an average firm size of 9.5 employees, that implies roughly 1,200 fewer employees.

Again, net employment change tends to be negligible and there is little employment change in firms that are active throughout the period. The offset to the additional rise in exits comes primarily from an increase in firm entry, shown in the final row of each panel. In two of the three states, entry rises by an additional 3 to 4 percent and this corresponds to employment levels that roughly counteract the job loss due to exit. For example, in New Jersey, entry rises 3.1 percent relative to bordering counties in other states. At an average firm size of 9.5 employees, this would correspond to just under 1,100 employees, roughly offsetting the impact of 1,200 employee job loss from firm exits.

There is no evidence that entry rises in California. Consequently, lost jobs due to firm exit led to the disemployment reported in table 2. In all three states, employment changes arising from entry and exit are an order of magnitude larger than the net employment change among continuing firms.

4.2 Statistics of U.S. Businesses

Table 5 reports results from the Census' SUSB dataset. There are two panels differentiated by measures of Y_{st}: panel A is based on counts of establishment, panel B on employment. The first two rows of each report the elasticities associated with $\{\beta_0, \beta_1\}$, with corresponding cluster-corrected standard errors in parentheses. The third row reports the sum $\beta_0 + \beta_1$, the elasticity in the year after the minimum wage increase. Regressions are estimated using

weighted least squares, where the weights are the state's initial number of establishments or employment at the beginning of the year.

Column (1) shows the effects of the minimum wage on changes in net employment relative to total employment. A 1 percent minimum wage increase causes net employment to fall by -0.503 (0.307) percent in the year of the hike but increase by 0.256 (0.528) in the year after. Neither estimate is statistically distinguishable from zero.[6] While the results appear consistent with a small decline in net employment found in the literature, the data are not powerful enough to precisely estimate employment effects of this size.

The effect of the minimum wage on firm establishment and employment dynamics are reported in the remainder of the table. Births (column 2) are flat during the initial year of the minimum wage increase but rise notably in the year after. In particular, the share of new establishments rises by 0.156 (0.072) percent and the share of employees in these new establishments rises by 0.268 (0.096) percent, in the year after a 1 percent increase in the minimum wage. The results are similar if we include establishments with less than 100 employees or use OLS or median regression rather than WLS. Moreover, there is no increase in small firm births in the rest of the economy, defined as industries other than accomodations and food services (column 6).

Column (3) presents results for establishment closures. Again, we find an increase in firm deaths, particularly in the year after the minimum wage increase. A 1 percent increase in the minimum wage causes the share of establishments that close to rise by 0.177 (0.054) percent and the share of employees in these closed establishments to rise by 0.222 (0.079) percent in the year after the hike. This result is also robust to alternative firm size definitions and regression methods, although there is some evidence that establishment deaths rise in other industries as well (column 7). The birth and death elasticities are of comparable economic magnitude. Moreover, we find little evidence that the minimum wage impacted continuously active firms, whether they are expanding (column 4) or contracting (column 5) employment. Consequently, the net impact on employment is small.

[6] Results are similar when we use OLS and median regression.

5 The Putty-Clay Model

This section develops a model of firm dynamics based on putty-clay technology. When a restaurant enters, it can freely choose its input mix from a putty and flexible technology. The novel feature of the putty-clay model is that after entry the technology hardens to clay and the input mix is fixed for the life of the restaurant.

The putty-clay nature of technology introduces an asymmetry between incumbent firms and potential entrants: incumbent firms have a fixed input mix optimized for the old minimum wage, while potential entrants have a fixed input mix optimized for the new minimum wage. This asymmetry is the basis for the model's unique prediction of the possibility of a spike in entry following a minimum wage hike: some of the incumbents who exit to be replaced by new entrants would not exit if they could adjust their input mix. The additional exit of these incumbents who are replaced by the flexible potential entrants generates the possibility of the spike in entry.

5.1 Production

Restaurants produce food using four inputs: capital, high-skill labor, low-skill labor and materials. Capital includes land, structures and machinery and low-skilled labor is minimum wage labor.

5.1.1 Production Technology

Ex ante, restaurants can flexibly substitute between inputs. Restaurants purchase technology from a CES production function,

$$y = A_j(\alpha_k k^{\frac{\sigma-1}{\sigma}} + \alpha_m m^{\frac{\sigma-1}{\sigma}} + \alpha_h h^{\frac{\sigma-1}{\sigma}} + (1-\alpha) l^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}},$$

where $\alpha = \alpha_k + \alpha_m + \alpha_h$ so that it is constant returns to scale, A_j is the productivity of a restaurant aged j, σ is the elasticity of substitution, k is capital, m is materials, h is high skill labor and l is low skill labor.

Ex post, the production function is Leontief and restaurants cannot substitute between inputs. Let k', m', h' and l' denote the initial input choices. In subsequent periods the

production function is:

$$y = \begin{cases} A_j(\alpha_k k'^{\frac{\sigma-1}{\sigma}} + \alpha_m m'^{\frac{\sigma-1}{\sigma}} + \alpha_h h'^{\frac{\sigma-1}{\sigma}} + (1-\alpha) l'^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}} & \text{if } k \geq k', l \geq l', h \geq h', m \geq m' \\ 0 & \text{otherwise.} \end{cases}$$

5.1.2 Productivity Process

Once a restaurant has entered, it gradually becomes less productive. A restaurant that is j old has total factor productivity (TFP) $A_j = e^{-\delta j}$, where δ is the deterministic TFP depreciation term.

5.2 Restaurant Maximization

A restaurant is the bundle of inputs that produces y_0 when it enters. A restaurant makes two decisions at entry: what input mix to choose, and what exit rule to follow.

5.2.1 Factor Demands

Since the restaurant is not free to adjust its input mix once capital is installed, the initial choice of input mix is a forward looking decision and the relevant factor prices are the effective factor prices over the life of the restaurant. An entering restaurant solves the following maximization problem:

$$max_{k,m,h,l,J} q_p(\alpha_k k^{\frac{\sigma-1}{\sigma}} + \alpha_m m^{\frac{\sigma-1}{\sigma}} + \alpha_h h^{\frac{\sigma-1}{\sigma}} + (1-\alpha) l^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}} - q_w l - q_m m - q_h h - q_k k, \quad (2)$$
$$\text{subject to } (\alpha_k k^{\frac{\sigma-1}{\sigma}} + \alpha_m m^{\frac{\sigma-1}{\sigma}} + \alpha_h h^{\frac{\sigma-1}{\sigma}} + (1-\alpha) l^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}} = y_0$$

where r is the interest rate, J is the exit age, $q_p = \int_0^J e^{-(r+\delta)t} P dt$ is the effective output price, $q_m = \int_0^J e^{-rj} p_m dt$ is the effective materials price, $q_h = \int_0^J e^{-rj} w^h dt$ is the effective high skill wage, $q_k = p_k(1 - e^{-rJ}\eta)$ is the effective capital price and $q_w = \int_0^J e^{-rt} w dt$ is the effective minimum wage. The capital price takes a different form than other input prices because capital is purchased once and then resold at a discount of $1 - \eta$ when the restaurant exits, whereas other inputs are paid for on a flow basis.

Maximization of (2) implies factor demands, which depend on J, the exit age:

$$l = \frac{y_0}{[\alpha_k \left(\frac{\alpha_k}{1-\alpha}\frac{q_w}{q_k}\right)^{\sigma-1} + \alpha_m \left(\frac{\alpha_m}{1-\alpha}\frac{q_w}{q_m}\right)^{\sigma-1} + \alpha_h \left(\frac{\alpha_h}{1-\alpha}\frac{q_w}{q_h}\right)^{\sigma-1} + (1-\alpha)]^{\frac{\sigma}{\sigma-1}}},$$

$$k = l\left(\frac{\alpha_k}{1-\alpha}\frac{q_w}{q_k}\right)^{\sigma}, m = l\left(\frac{\alpha_m}{1-\alpha}\frac{q_w}{q_m}\right)^{\sigma}, h = l\left(\frac{\alpha_h}{1-\alpha}\frac{q_w}{q_h}\right)^{\sigma}. \tag{3}$$

5.2.2 Exit Age

The restaurant exits when the marginal cost of producing exceeds the marginal benefit. An exiting restaurant sells its capital for $\eta p_k k$ where $\eta \in [0,1]$ and ηp_k is the salvage value of a unit of capital. The shadow cost of delaying the sale of capital for a unit of time is $r\eta p_k k$. The total flow marginal cost of operating is $r\eta p_k k + hw_h + mp_m + lw$. In steady state with deterministic depreciation, the marginal benefit of operating a restaurant at age j is $e^{-\delta j} y_0 P$, which is quantity times price.[7]

Because the flow marginal benefit of producing declines over time while the marginal cost is constant, the restaurant eventually exits. The exit age J equates the marginal cost and marginal benefit of operating:

$$e^{-\delta J} P y_0 = r\eta p_k k + hw_h + mp_m + lw. \tag{4}$$

Given the market price P and factor prices, substituting the restaurant's factor demands (equation (3)) into the exit age equation (equation (4)) results in one equation in one unknown and so this solves the restaurant's problem in steady state.

5.3 Market Price Determination

In steady state, free entry pins down the market price. A restaurant's expected (and realized) profit in steady state is:

$$\pi = q_p(\alpha_k k^{\frac{\sigma-1}{\sigma}} + \alpha_m m^{\frac{\sigma-1}{\sigma}} + \alpha_h h^{\frac{\sigma-1}{\sigma}} + (1-\alpha) l^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}} - q_w l - q_m m - q_h h - q_k k. \tag{5}$$

[7] In a stochastic environment there would be an additional option value term.

Let f denote the steady state mass of entrants each period. The free entry condition is that either expected profits or entry is zero:

$$\pi f = 0. \tag{6}$$

In steady state there is entry so that profits are zero. Zero profits, the exogenously given factor prices and the solution to the restaurant's problem mean that equation (5) is one equation in one unknown, the product price.

5.4 Market-Level Equilibrium

The industry faces an isoelastic product demand curve:

$$Q = \theta P^{-\gamma}. \tag{7}$$

Product market clearing implies that quantity demanded equals quantity supplied:

$$Q = \int_0^J e^{-j\delta} y_0 f dj, \tag{8}$$

where the components of supply are that a restaurant of vintage j supplies quantity $e^{-\delta j} y_0$, f is the density of each vintage of restaurant (and the mass of entrants each period), and J is the mass of different vintages of restaurants producing. Integrating (8) and rearranging provides an explicit solution to the steady state mass of restaurants that enter in every time period:

$$f = \frac{\delta Q}{y_0(1 - e^{-J\delta})}. \tag{9}$$

Entry and exit dynamics derive from the lifecycle of a restaurant. In steady state, the same mass of restaurants enter and exit in every period. Hence, exit and entry rates are both the inverse of the life of a restaurant: $\frac{1}{J}$.

5.5 Steady State Equilibrium

A steady state equilibrium is given by endogenous objects $\{k, h, m, l, Q, P, J, f\}$ taking factor prices $\{p_k, p_m, w_h, w\}$ and the environment $\{\delta, \eta, \theta, \gamma, \sigma, r, \alpha_k, \alpha_m, \alpha_h, \alpha_l, y_0\}$ as given such

that:

- Firms maximize (equation (2));
- Free entry holds (equation (6)); and
- The product market clears (equation (8)).

6 A Minimum Wage Hike

A permanent minimum wage hike from w^o to w^n at time T affects the market through two channels. The first channel is the scale effect: the equilibrium market price of output rises, the equilibrium quantity of output falls and so demand for all inputs contracts. The second channel is the substitution effect: a hike in the minimum wage makes low-skilled workers relatively more expensive. While these Hicks-Marshall channels are normally computed in a static model, in this dynamic model the two effects unfold over different horizons, which give rise to rich dynamics of restaurant behavior.

The scale effect occurs in a way most similar to the static case: if there is gross entry, then the market price and quantity immediately adjust to the new steady state level. There is net exit of restaurants immediately following a minimum wage hike and consequently an immediate fall in the employment of minimum wage workers.

The unfolding of the substitution effect derives from the asymmetry between the incumbents and potential entrants. Because the incumbent restaurants that remain in the industry maintain their input mix, the substitution effect occurs gradually as the incumbent restaurants exit and are replaced by new restaurants that are free to choose the optimal input mix given the new price of minimum wage labor.

6.1 Exit Dynamics

6.1.1 Overview

There are two central questions about exit behavior following a minimum wage hike: first, when is there an increase in exit? Second, what is the contribution of putty-clay technology to the exit behavior?

There is an increase in exit following a minimum wage hike when the increase in low-skill labor costs (marginal cost) at incumbent restaurants is not offset by the increase in market price (marginal benefit), which is true when there is $ex - ante$ substitutability in the production function ($\sigma > 0$). Then the marginal benefit of operating curve crosses the marginal cost of operating curve earlier in a restaurant's life and there is a one-time increase in exit.

The increase in exit can be decomposed into a "standard" component and a "putty-clay" component. The standard component is the number of restaurants that would exit even if they could adjust their input mix. The "putty-clay" component is due to the asymmetry introduced by putty-clay technology: exit that occurs only because the input mix is fixed. The contribution of the putty-clay component is increasing in the elasticity of substitution of the ex-ante technology. When the elasticity of substitution is one all the increase in exit is due to putty-clay effects; when the elasticity of substitution is greater than one then the "standard" component predicts a *decline* in exit and so putty-clay effects make up for the decline and account for all of the increase.

6.1.2 Exit Behavior

The exit behavior of incumbents depends on the relative magnitudes of the increase in the marginal cost and the marginal benefit of operating. In a static model, because the price elasticity and the cost elasticity with respect to the minimum wage are both labor share, s_L, these effects exactly offset so there is no exit. In the model in this paper, these changes do not offset because part of the capital cost is sunk. The labor share in the $flow$ marginal cost of operating used to make the exit decision is always larger than the labor share in expenses over the life of the restaurant and so restaurants exit early.[8]

Since the incumbent restaurants have already picked their input mix, the only margin on which they can respond is by exiting earlier (or later). As in steady state, because the marginal benefit of operating is falling, the exit age is determined by when the marginal benefit of operating equals the marginal cost. Letting $J(w^o, w^n)$ be the exit age of a restaurant that entered when the steady state was given by w^o but is deciding to exit when the minimum

[8] We show below that labor share in expenses over the life of the restaurant is not equal to the price elasticity except in the Cobb Douglass case, but the intuition carries over.

wage is w^n, the restaurant exits when the following equation holds:

$$e^{-\delta J(w^o,w^n)} P^n y_0 = r\eta p_k k^o + h^0 w_h + m^o p_m + l^o w^n. \tag{10}$$

Result 2 in Appendix B shows that so long as $\sigma > 0$ then $J(w^o, w^n) < J(w^o, w^o)$.

The spike in gross exit is given by:

$$\int_{J(w^o,w^n)}^{J(w^o,w^o)} f^o dt = f^o(J(w^o, w^o) - J(w^o, w^n)), \tag{11}$$

where f_o is the old steady state number of firms. This expression measures the mass of restaurants that were viable at the old minimum wage and the old market price, but are not viable at the new prices.

The minimum wage hike means that all incumbent firms exit earlier than planned but there is the same density of incumbent firms of any given age. As a result, following the spike in exit, the density of firms exiting in a given period remains the same as before the minimum wage hike until all of the incumbent firms have exited. Formally, then, the mass of exit in a time width Δ is

$$f_o \Delta.$$

The difference in the exiting behavior relative to before the minimum wage hike is that the restaurants produce more just before they exit, because they are exiting when they are younger. This means that the market quantity that these restaurants take out of production is larger, and so they open up more space in the market.

In the data, the average life of a restaurant is approximately 7 years, so that this discussion encompasses the relevant exit dynamics to match our empirical work. Appendix C provides a detailed discussion of exit dynamics.

6.1.3 Decomposing the exit spike

Taking as given the change in market price, we decompose the spike in exit into the "standard" component that would occur with flexible ex-post technology and the "putty-clay" that reflects the inflexibility of ex-post technology. Since the market price jumps to the new steady state and the new entrants pick the optimal technology given the new prices, the new

steady state exit age, $J(w^n, w^n)$, provides the age at which incumbents would exit even if their technology was flexible. Hence, the standard component of exit is:

$$f^o(J(w^o, w^o) - J(w^n, w^n)). \tag{12}$$

The relationship between $J(w^o, w^o)$ and $J(w^n, w^n)$ depends on the ex ante elasticity of substitution. When $\sigma < 1$ then newly entering restaurants have less possibility of substituting away from labor. This means that the relative importance of capital decreases with a minimum wage increase, less of the input costs are sunk, and so the restaurant exits earlier. When $\sigma > 1$, then newly entering restaurants can substitute more from labor and into other inputs, including capital. The increased use of capital means that more of the input costs are sunk and so in steady state exit is delayed. When $\sigma = 1$, there is no change in the exit age.

Together, this implies that the standard component is signed as follows:

$$f^o(J(w^o, w^o) - J(w^n, w^n)) \begin{cases} > 0 & \text{if } \sigma < 1 \\ = 0 & \text{if } \sigma = 1 \\ < 0 & \text{if } \sigma > 1. \end{cases}$$

The putty-clay component is the set of restaurants that exit who would not if they could adjust their input mix. In this case, it is those restaurants that exit at an age younger than the new steady state exit age:

$$f^o(J(w^n, w^n) - J(w^o, w^n)). \tag{13}$$

A cost minimization argument shows that for $0 < \sigma < 1$ $J(w^o, w^n) < J(w^n, w^n)$ and for $\sigma \geq 1$ $J(w^o, w^n) < J(w^n, w^n) \leq J(w^o, w^o)$ so that the putty-clay component is (almost) always positive. Since in the Cobb-Douglas case the standard component is zero, any exit in this case comes from the putty-clay dynamics. Similarly, when $\sigma > 1$ then more than 100% of the exit comes from putty-clay dynamics.

6.2 Entry Dynamics

The entry dynamics following a minimum wage hike are determined by the exiting firms since the entering firms fill up the gap in market quantity left by the exiting firms.

There are two potential sources of an increase in entry. First, there can be a spike in entry similar to the spike in exit at the instant the minimum wage hike is implemented if the exit spike is large enough. If the following inequality holds

$$e^{-J(w^n,w^o)\delta} y_0 f^o(J(w^o,w^o) - J(w^n,w^o)) > Q^o - Q^n$$

then the exiting firms take more capacity out of production than is mandated by the scale effect and there is room for an increase in entry. Second, following the spike, incumbent firms exit earlier and so a given exit takes more capacity out of production than before the hike while the number of exits remains the same. Total exit then takes more capacity out of production than before the hike and so the number of entering firms increases.

Appendix C provides a detailed discussion of entry behavior.

6.2.1 Decomposing the entry spike

As with exit, we can decompose entry into the "standard" component and the "putty-clay" component again taking the path of market prices as given by the putty-clay model. The standard component of entry is the share of the spike in entry that is due to the standard component of the spike in exit. All of the rest of the increase in entry is due to putty-clay effects.

7 Calibration

We calibrate the model to the restaurant industry. Two issues arise in our calibration that merit comment. First, because we are using a CES production function there is not a direct map from factor shares to the α_j, since the factor shares also depend on the relative prices. Second, in the model the capital share in revenue is declining over time. This means that we target the "average" capital share.

The factor shares follow those in Aaronson and French (2007) at table 1. The materials,

capital and labor share are the middle of the ranges from that table. The division between high and low skill labor is as follows: $\frac{1}{3}$ of workers are minimum wage workers, and they account for 17% of the wage bill. This implies that minimum wage workers have a 5.7% share in expenses overall. However, 70% of workers are low skill. Since the model assumes that all low skill workers are minimum wage workers but clearly some of them are not, we set $s_L = 0.1$, which implies that 58% of workers are minimum wage workers if they earn the minimum wage. Since total labor share is 0.3 this implies that $s_H = 0.2$. The average wages of the high skill workers thus have to be such that 42% of the workforce earns two thirds of the wage bill. This implies that $\frac{w_H.42}{w_H.42+.58w} = \frac{2}{3}$ or $w_H = 2\frac{.58}{.42}w = 2.76w$.

We compute the average life of a restaurant from data. Table 6 summarizes the targets and resulting values and table 7 shows the parameter values in the model that these are based on.

We calibrate $\{\sigma, p_m, p_k, w, w_h\}$ externally. Then we use minimum distance techniques to pick $\{\alpha_k, \alpha_m, \alpha_h, \eta\delta, \gamma\}$ to match the elasticity of entry and exit with respect to the minimum wage increase. We compute the elasticity on the basis of a 20% minimum wage increase.

8 Calibration Results

8.1 Entry and Exit Behavior in Steady State

We first illustrate the steady state behavior of the model. Figure 1 shows the determination of exit age of a firm. The marginal cost of operating is constant over the life of the firm because factor prices are constant and input choices are fixed for the life of the restaurant. The marginal benefit of operating, however, declines over the life of the restaurant. The reason is that the deterministic TFP decline means that the same bundle of inputs produces less and less output. The restaurant exits when the marginal benefit of operating hits marginal cost.

8.2 The effect of a minimum wage hike on market price, quantity and employment

We study a 20% one-time, unanticipated and permanent minimum wage hike from steady state.[9] Figure 2 shows the behavior of market price, quantity and employment following the minimum wage hike. Because there is still entry, the product price jumps to the new steady state value when the minimum wage is increased. The elasticity is 0.08, which is in line with the evidence discussed in Aaronson and French (2007). Because the market price jumps immediately, the market quantity jumps to its new steady state level as well, which is implied by the product demand curve (equation (7)).

Employment responds slowly to the minimum wage hike. After one year, the elasticity of total employment (high and low skill) is -0.11. The employment response grows over time such that in the steady state determined by the new minimum wage, the final elasticity is -0.47. This graph illustrates a key feature of the putty-clay model: because firms turn over slowly following a minimum wage hike, the full employment effect of the minimum wage also unfold slowly.

8.3 The effect of a minimum wage hike on entry and exit behavior

While the novel empirical result in this paper pertains to entry behavior following a minimum wage hike, the key to understanding entry behavior in the model is understanding exit behavior. The reason is that the path of market quantity follows from the free entry condition and so the amount of entry depends on the amount of exit.

Figure3 illustrates the exit decision of an incumbent firm. The marginal benefit of operating at every age rises compared to before the hike because the market price rises. This rise in the market price, however, is not enough to compensate the firm for the increase in the wage. The marginal cost curve, which includes minimum wage labor, rises by enough so that the firm exits earlier than it would have otherwise. In particular, there is a mass of firms caught between the old and the new exit age who exit early. This mass of firms is the spike in exit.

The upper panel of Figure 4 shows the total amount of exit following the minimum wage

[9] We study a 20% minimum wage hike because the model is nonlinear.

hike, while the lower panel shows the entry behavior. So long as product demand is elastic, the exit rate is higher than the entry rate because market quantity falls. However, the spike in exit is sufficient to allow a significant spike in entry.

8.4 The contribution of putty-clay to entry and exit behavior

In the calibration, 96% of the exit elasticity is due to putty-clay effects, while over 200% of the entry elasticity is due to putty-clay effects, since in the absence of putty-clay technology there is a decline in entry following a minimum wage hike.

Figure 5 shows the total amount of exit and entry that would occur in the absence of putty-clay technology with the exit and entry that occurs with putty-clay technology. In the absence of putty-clay technology, there is still a spike in exit.[10] However, this spike is much smaller than in the presence of putty-clay technology. Figure 6 illustrates the marginal cost curves for incumbents with and without putty-clay technology. Without putty-clay technology the incumbents can substitute away from minimum wage labor, reducing the impact of the minimum wage hike on costs and resulting in a smaller rise in marginal cost. The shift in the marginal benefit curve is identical with and without putty-clay technology because firm output is constant and in either equilibrium the market price is set by the new, flexible entrants. The smaller rise in marginal cost means that the mass of incumbents that exit early is much smaller without putty-clay technology.

The smaller exit response generated by the model without putty-clay technology means that the entry response is smaller. In fact, entry drops. This drop in entry is a robust qualitative feature of the way entry and exit are modeled in this paper without putty-clay technology. Hence, putty-clay technology is central to understanding the rise in entry.

9 Conclusion

We present new evidence on the effect of minimum wage hikes on establishment entry, exit, and employment among employers of low-wage labor. We show that small net employment changes in the restaurant industry may hide a significant amount of firm level churning that

[10] This is true as long as $\sigma < 1$. When $\sigma > 1$ the price rises by more and so there is always a fall in entry without putty-clay technology.

arises in response to a minimum wage hike. In particular, increases in the minimum wage induce greater firm exit, a result consistent with many existing models. However, more surprising, we find a simultaneous and roughly offsetting increase in firm entry. To capture these dynamics, we extend a putty-clay model to incorporate endogenous exit. The key feature of the putty-clay model is that, after entry, technology and input mix is fixed for the life of the firm. This introduces the possibility that inflexible incumbents are replaced by potential entrants who can optimize on input mix. Thus, the model is capable of predicting both firm entry and exit in response to a minimum wage hike. Moreover, Sorkin (2013) shows that putty-clay models are able to match other previously known facts about the short- and long-run employment and price responses to minimum wage changes.

10 Tables

Table 1: State minimum wage increases

		Minimum Wage			
Year	State	Old	New	% Change	Comparison States
Jan. 01	CA	5.75	6.25	8.7	OR, NE, AZ
Jan. 02	CA	6.25	6.75	8	OR, NE, AZ
Jan. 04	IL	5.15	5.5	6.8	IN, IA, KY, MO
Jan. 05	IL	5.5	6.5	18.2	IN, IA, KY, MO
Oct. 05	NJ	5.15	6.15	19.4	DE, PA
Oct. 06	NJ	6.15	7.15	16.3	DE, PA

Source: Monthly Labor Review, January Issues.
QCEW data is not available for New York and therefore is not included among the New Jersey comparison states.

Table 2: Employment effects from a minimum wage change, all firms

	Interior Counties (1)	Border Counties (2)	< 50 Travel Miles (3)	< 25 Travel Miles (4)
		California		
Annualized employment change	-0.093	-0.091	-0.038	-0.116
	(0.049)	(0.072)	(0.27)	(0.31)
Minimum wage elasticity	-0.036	-0.030	-0.013	-0.038
Wage elasticity	-0.090	-0.075	-0.031	-0.096
Initial establishment size	14.9	17.4	N/A	N/A
Sample Size	23730	6480	169	109
		Illinois		
Annualized employment change	0.099	0.102	0.117	0.0509
	(0.084)	(0.052)	(0.046)	(0.059)
Minimum wage elasticity	0.023	0.029	0.033	0.014
Wage elasticity	0.058	0.072	0.082	0.036
Initial establishment size	16.3	13.6	N/A	N/A
Sample Size	4215	10693	6609	3300
		New Jersey		
Annualized employment change	0.081	0.039	-0.041	-0.045
	(0.062)	(0.054)	(0.037)	(0.053)
Minimum wage elasticity	0.022	0.011	-0.011	-0.012
Wage elasticity	0.056	0.026	-0.028	-0.030
Initial establishment size	9.3	9.5	N/A	N/A
Sample Size	6456	7455	5125	1711

OLS standard errors in parentheses. Border counties are those that physically touch the relevant state border. Travel miles computed as closest other establishment using road distances reported by mapquest.com. Wage elasticities assume that 40 percent of limited service establishments are impacted by changes in the minimum wage.

Table 3: Employment effects from a minimum wage change, continuously active firms

	Interior Counties	Border Counties	< 50 Travel Miles	< 25 Travel Miles
	(1)	(2)	(3)	(4)
		California		
Annualized employment change	0.125	0	Too Few	Too Few
	(0.062)	(0.088)		
Minimum wage elasticity	0.038	0	N/A	N/A
Wage elasticity	0.096	0	N/A	N/A
Initial establishment size	18.7	22.2	N/A	N/A
Sample Size	7182	1942	N/A	N/A
		Illinois		
Annualized employment change	0.164	0.042	0.017	-0.023
	(0.089)	(0.056)	(0.039)	(0.050)
Minimum wage elasticity	0.031	0.009	0.004	-0.005
Wage elasticity	0.077	0.024	0.010	-0.013
Initial establishment size	20.4	17	N/A	N/A
Sample Size	1771	4217	3046	1546
		New Jersey		
Annualized employment change	0.087	-0.219	-0.015	-0.137
	(0.073)	(0.069)	(0.063)	(0.084)
Minimum wage elasticity	0.017	-0.042	-0.003	-0.026
Wage elasticity	0.044	-0.104	-0.007	-0.065
Initial establishment size	12.8	13.5	N/A	N/A
Sample Size	2022	2191	1450	532

OLS standard errors in parentheses. Border counties are those that physically touch the relevant state border. Travel miles computed as closest other establishment using road distances reported by mapquest.com. Wage elasticities assume that 40 percent of limited service establishments are impacted by changes in the minimum wage.

Table 4: Firm entry and exit after a minimum wage change

	Interior Counties (1)	Border Counties (2)	< 50 Travel Miles (3)	< 25 Travel Miles (4)
		California		
Change in firm exit	0.044	0.045	0.067	0.076
	(0.011)	(0.015)	(0.055)	(0.061)
Change in firm entry	0.007	-0.017	-0.005	-0.001
	(0.007)	(0.01)	(0.033)	(0.036)
Firms with initial positive employment	13685	3605	94	60
		Illinois		
Change in firm exit	0.012	0.049	0.006	0.002
	(0.015)	(0.011)	(0.008)	(0.009)
Change in firm entry	0.019	0.036	0.025	0.019
	(0.011)	(0.008)	(0.006)	(0.007)
Firms with initial positive employment	2745	6922	4809	2358
		New Jersey		
Change in firm exit	0.063	0.07	0.071	0.062
	(0.015)	(0.013)	(0.011)	(0.017)
Change in firm entry	0.028	0.031	0.014	0.015
	(0.01)	(0.009)	(0.008)	(0.011)
Firms with initial positive employment	3812	4385	2927	1011

OLS standard errors in parentheses. Border counties are those that physically touch the relevant state border. Travel miles computed as closest other establishment using road distances reported by mapquest.com.

Table 5: Establishment Dynamics: 1-19 Employees

			NAICS 72			All Other Industries	
	Net employment	Births	Deaths	Expansions	Contractions	Births	Deaths
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	A. Outcome variables=establishments						
β_0		-0.070	0.089	-0.117	0.076	-0.095	0.112
		(0.059)	(0.050)	(0.053)	(0.048)	(0.064)	(0.065)
β_1		0.226	0.088	0.020	−0.029	0.069	0.04
		(0.109)	(0.063)	(0.098)	(0.077)	(0.082)	(0.067)
$\beta_0 + \beta_1$		0.156	0.177	−0.097	0.047	-0.026	0.152
		(0.072)	(0.054)	(0.096)	(0.103)	(0.092)	(0.076)
N		525	525	525	525	525	525
	B. Outcome variables=employment						
β_0	-0.503	-0.015	0.070	-0.108	0.093	-0.074	-0.219
	(0.307)	(0.069)	(0.059)	(0.093)	(0.062)	(0.117)	(0.273)
β_1	0.756	0.283	0.152	0.155	-0.053	-0.002	0.325
	(0.525)	(0.093)	(0.075)	(0.125)	(0.111)	(0.125)	(0.225)
$\beta_0 + \beta_1$	0.253	0.268	0.222	0.047	0.040	-0.076	0.106
	(0.528)	(0.096)	(0.079)	(0.149)	(0.100)	(0.117)	(0.135)
N	525	504	509	525	525	497	491

Notes: Estimates are from a WLS regression of the outcome on the level of the state minimum wage and its lead, year dummies, and state dummies. All outcomes are normalized by initial numbers of firms or employment. An observation is a state-year. 25 state-years with an automatic CPI adjustment are deleted. This leaves 525 observations for outcomes based on establishment counts. 21 state-years are missing for employment due to births and 16 are missing for employment due to deaths, leaving 504 and 509 state-year observations, respectively. The minimum wage is from January of each year. Standard errors are clustered at the state level.

Table 6: Calibration Targets and Results

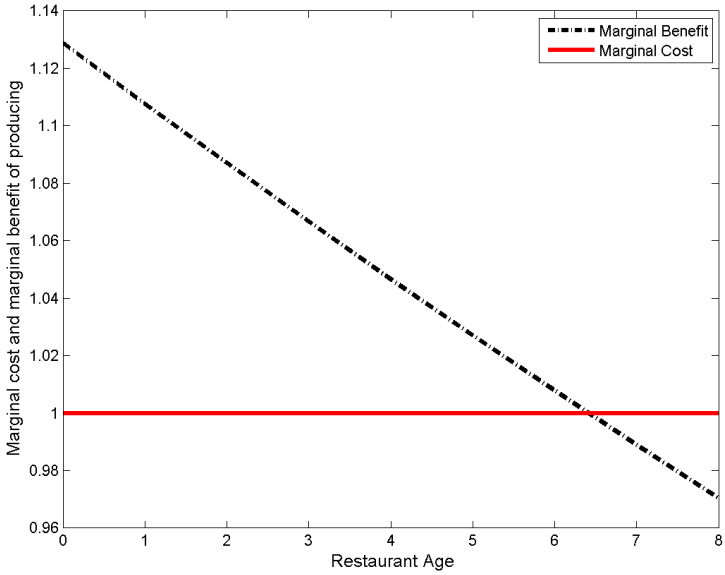
Moment	Target	Result	Description
s_L	0.1	0.0999	Low-skill labor share
s_H	0.2	0.2035	High-skill labor share
s_M	0.4	0.3980	Materials share
s_K	0.3	0.2986	Capital share
J	6.7	6.6931	Average life of a restaurant
Exit Spike	0.18	0.2008	
Entry Spike	0.08	0.0800	

Table 7: Calibration

Moment	Value	Description
r	0.0513	Interest Rate
δ	0.0236	Depreciation Rate
η	0.9052	Resale Price
α_k	0.3704	
α_h	0.1394	
α_m	0.4206	
w	1	Minimum Wage
p_k	29	Capital Price
w_h	2.76	High Skill Wage
p_m	1	Materials Price
σ	0.8	Elasticity of Substitution
γ	0.5	Elasticity of Product Demand

11 Figures

Figure 1: Determination of exit age in steady state

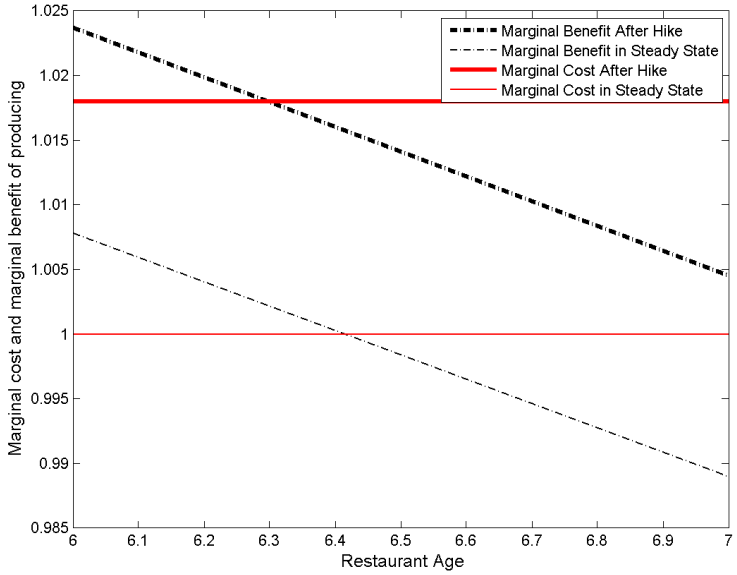


Note: .

Figure 2: Market-level variables after a minimum wage hike

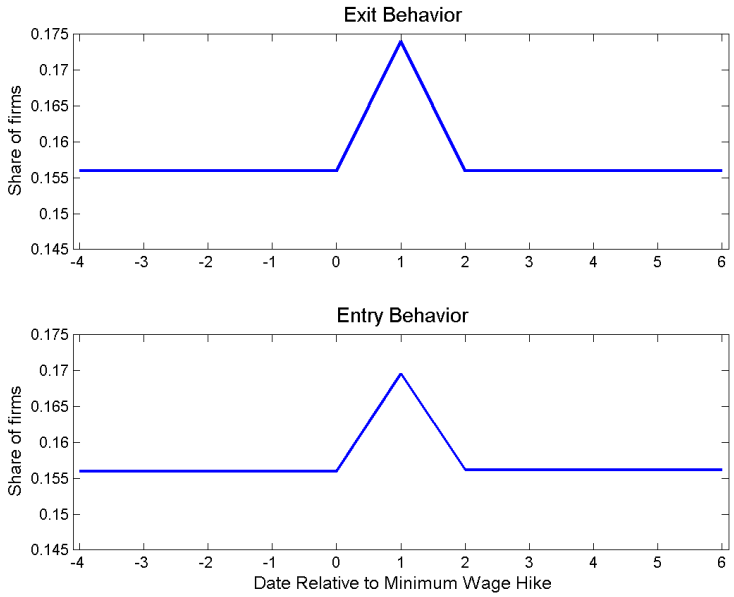
Note: .

Figure 3: Exit decision of incumbents after a minimum wage hike



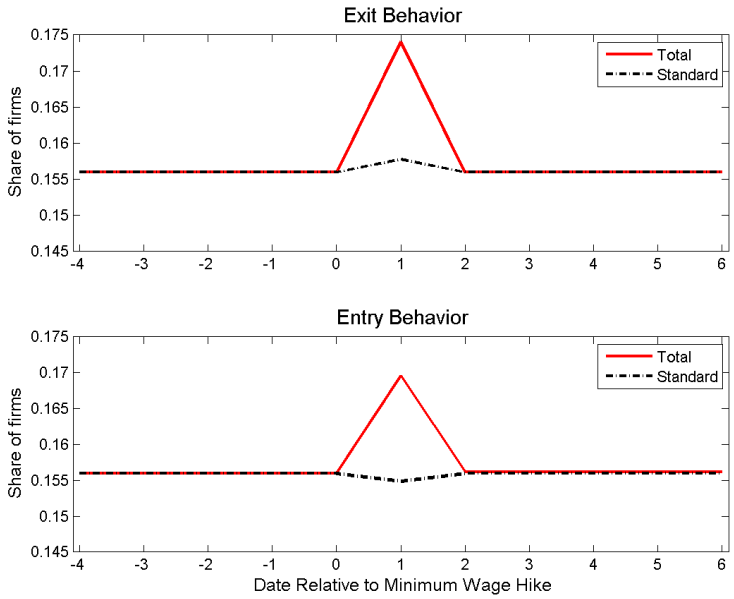
Note: .

Figure 4: Aggregate entry and exit after a minimum wage hike



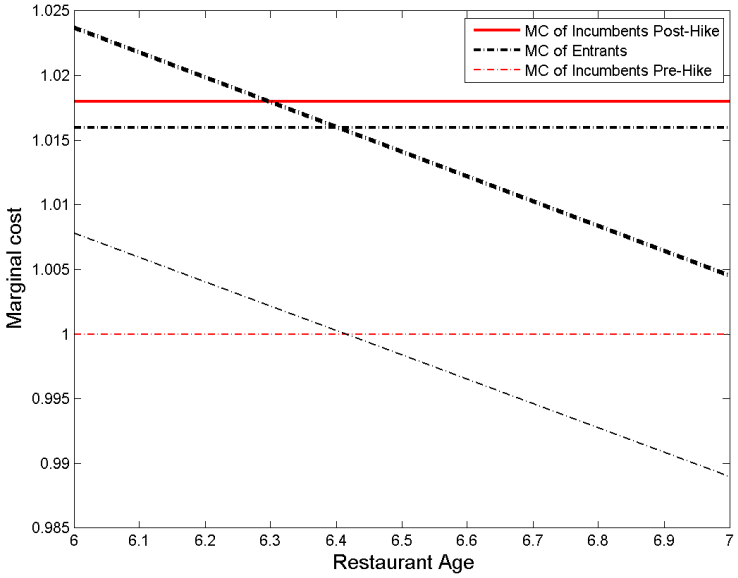
Note: .

Figure 5: Decomposition of entry and exit after a minimum wage hike



Note: .

Figure 6: Contribution of putty-clay to shift in cost curves



Note: .

Appendix A: Deriving the Effective Product Price

Free entry implies that the maximand in (2) is equal to zero. Substituting in the equilibrium factor demands from equation (3) to the maximand in equation (2) set equal to zero:

$$
\begin{aligned}
q_p y_0 &= q_k k + q_h h + q_m m + q_w l \\
q_p &= \frac{q_k \left(\frac{\alpha_k}{1-\alpha}\frac{q_w}{q_k}\right)^{\sigma} + q_h \left(\frac{\alpha_h}{1-\alpha}\frac{q_w}{q_h}\right)^{\sigma} + q_m \left(\frac{\alpha_m}{1-\alpha}\frac{q_w}{q_m}\right)^{\sigma} + q_w}{\left[\alpha_k \left(\frac{\alpha_k}{1-\alpha}\frac{q_w}{q_k}\right)^{\sigma-1} + \alpha_m \left(\frac{\alpha_m}{1-\alpha}\frac{q_w}{q_m}\right)^{\sigma-1} + \alpha_h \left(\frac{\alpha_h}{1-\alpha}\frac{q_w}{q_h}\right)^{\sigma-1} + (1-\alpha)\right]^{\frac{\sigma}{\sigma-1}}} \\
q_p &= \frac{q_w}{1-\alpha} \frac{\alpha_k \left(\frac{\alpha_k}{1-\alpha}\frac{q_w}{q_k}\right)^{\sigma-1} + \alpha_h \left(\frac{\alpha_h}{1-\alpha}\frac{q_w}{q_h}\right)^{\sigma-1} + \alpha_m \left(\frac{\alpha_m}{1-\alpha}\frac{q_w}{q_m}\right)^{\sigma-1} + 1-\alpha}{\left[\alpha_k \left(\frac{\alpha_k}{1-\alpha}\frac{q_w}{q_k}\right)^{\sigma-1} + \alpha_m \left(\frac{\alpha_m}{1-\alpha}\frac{q_w}{q_m}\right)^{\sigma-1} + \alpha_h \left(\frac{\alpha_h}{1-\alpha}\frac{q_w}{q_h}\right)^{\sigma-1} + (1-\alpha)\right]^{\frac{\sigma}{\sigma-1}}} \\
q_p &= \frac{q_w}{1-\alpha} \left(\alpha_k \left(\frac{\alpha_k}{1-\alpha}\frac{q_w}{q_k}\right)^{\sigma-1} + \alpha_m \left(\frac{\alpha_m}{1-\alpha}\frac{q_w}{q_m}\right)^{\sigma-1} + \alpha_h \left(\frac{\alpha_h}{1-\alpha}\frac{q_w}{q_h}\right)^{\sigma-1} + (1-\alpha)\right)^{\frac{-1}{\sigma-1}}.
\end{aligned}
\tag{14}
$$

Appendix B: Results about post minimum wage hike exit.

The post minimum wage hike exit age is given by the solution to equation (10):

$$e^{-\delta J(w^o,w^n)} P^n y_0 = r\eta p_k k^o + h^o w_h + m^o p_m + l^o w^n. \tag{15}$$

Let $s_L^f = \frac{l^o w^o}{r\eta p_k k^o + h^o w_h + m^o p_m + l^o w^o}$.

Result 1. *If $\sigma > 0$ then $\frac{\partial P}{\partial w}\frac{w}{P} < \hat{s_L^f}$.*

Proof. Suppose that $\frac{\partial P}{\partial w}\frac{w}{P} > \hat{s_L^f}$. If in the new steady state restaurants choose the same input mix as in the old steady state, $k^n = k^o$, $h^n = h^o$, $m^n = m^o$, and $l^n = l^o$, then the restaurant's life span is the same, but at each age it earns more than it did in the old steady state. As a result, the restaurant earns positive profits and the free entry condition no longer holds (equation (6). A contradiction. So $\frac{\partial P}{\partial w}\frac{w}{P} \leq \hat{s_L^f}$.

Suppose towards a contradiction that $\frac{\partial P}{\partial w}\frac{w}{P} = \hat{s_L^f}$. If in the new steady state restaurants choose the same input mix as in the old steady state: $k^n = k^o$, $h^n = h^o$, $m^n = m^o$, and $l^n = l^o$, then the free entry condition holds (equation (6) since at each age the restaurants costs and benefits have gone up by the same amount. So long as there is ex ante flexibility in the production function ($\sigma > 0$), however, the entering restaurants can adjust their product mix and strictly increase profits, resulting in strictly positive profits, which violates the free entry condition (equation (6). Hence, $\frac{\partial P}{\partial w}\frac{w}{P} < \hat{s_L^f}$. □

Result 2. *If $\sigma > 0$, then $J(w^o, w^n) < J(w^o, w^o)$.*

Proof. The restaurant exit decision is given by the equality in equation (10):

$$e^{-\delta J(w^o,w^n)} P^n y_0 = r\eta p_k k^o + h^o w_h + m^o p_m + l^o w^n.$$

Suppose $J(w^o, w^n) > J(w^o, w^o)$. By result 1, the RHS rises by more than the LHS in response to a minimum wage hike, and since the LHS (marginal benefit) is strictly decreasing in age, the inequality cannot hold. Hence $J(w^o, w^n) \leq J(w^o, w^o)$.

Suppose $J(w^o, w^n) = J(w^o, w^o)$. By result 1, the RHS rises by more than the LHS in response to a minimum wage hike. As a result, the equality no longer holds. So $J(w^o, w^n) < J(w^o, w^o)$. □

Appendix C: Detailed Entry and Exit Dynamics Following a Minimum Wage Hike

Exit Dynamics

In the old steady state the number of firms that exit in a period interval Δ is:

$$\Delta f^o \tag{16}$$

and the implied output is:

$$\Delta e^{-\delta J(w^o,w^o)} f^o y_0. \tag{17}$$

The minimum wage increase results in an exit of firms with ages between $J(w^o, w^n)$ and $J(w^o, w^o)$. So the number of firms exiting is:

$$\int_{J(w^o,w^n)}^{J(w^o,w^o)} f^o dt = f^o(J(w^o, w^o) - J(w^o, w^n)). \tag{18}$$

The amount of output that exits is:

$$\int_{J(w^o,w^n)}^{J(w^o,w^o)} e^{-\delta t} y_0 f^o dt \tag{19}$$

$$= \frac{e^{-\delta J(w^o,w^n)} - e^{-\delta J(w^o,w^o)}}{\delta} f^o y_0.$$

Appendix **??** showed that when $\sigma < 1$ then $J(w^o, w^n) < J(w^n, w^n) < J(w^o, w^o)$. Then in the interval $(T, T + J(w^o, w^n)]$ only the old firms exit. Hence, the number of firms exiting is:

$$\Delta f^o \tag{20}$$

The output that exits is higher because the firms are less "depreciated" so that the output that exits is:

$$\Delta f^o e^{-\delta J(w^o,w^n)} y_0. \tag{21}$$

After time $T + J(w^o, w^n)$ all of the old firms have exited. In the interval $(T + J(w^o, w^n), T + J(w^n, w^n))$ the old firms do not exit and nor do the new firms. Hence, there is zero numbers of exits and zero quantity. Table A2 summarizes this discussion.

Entry Dynamics

In the old steady state the number of entrants is:

$$\Delta f^o \tag{22}$$

and entry output is

$$\Delta f^o y_0. \tag{23}$$

At implementation, the market quantity declines from Q^o to Q^n. Hence, the entry at implementation must accomodate this decline. So the output that is replaced is:

$$\frac{e^{-\delta J(w^o,w^n)} - e^{-\delta J(w^o,w^o)}}{\delta} f^o y_0 + (Q^n - Q^o) \tag{24}$$

which in turns implies that the number of entrants is:

$$\frac{\frac{e^{-\delta J(w^o,w^n)} - e^{-\delta J(w^o,w^o)}}{\delta} f^o y_0 + (Q^n - Q^o)}{y_0}. \tag{25}$$

For $(T, T + J(w^o, w^n))$ entry needs to cover the exiting output and the depreciation of existing output.

$$\Delta \left\{ e^{-\delta J(w^o,w^n)} f^o y_0 + \delta Q^n \right\} \tag{26}$$

so that the entering number is

$$\frac{\Delta \left\{ e^{-\delta J(w^o,w^n)} f^o y_0 + \delta Q^n \right\}}{y_0} \tag{27}$$

Finally, in $(T + J(w^o, w^n), T + J(w^n, w^n))$ the entry just replaces the depreciation.

So that the output is:

$$\Delta \delta Q^n \tag{28}$$

and the resulting number is

$$\Delta \frac{\delta Q^n}{y_0}. \tag{29}$$

Table A3 summarizes this discussion.

Appendix D: Demonstrating the Equivalence of the ES-202 and SUSB entry and exit estimates

The ES-202 data is establishment-level while the SUSB data is state-level. The appendix first demonstrates that our panel data model (equation (1)) is equivalent to a difference-in-difference estimator with measurements three years apart. This appendix then demonstrates that the regressions that we estimate on panel data imply the same conditional expectations in the ES-202 and SUSB data. For concreteness, we describe the reconciliation in the case of exit.

We first demonstrate that a difference-in-difference estimator for outcomes three years apart is equivalent to the panel regression presented in equation (1), which we reproduce here:

$$Y_{st} = \sum_{j=0}^{1} \beta_j w_{st-j} + a_t + a_s + \epsilon_{st}. \tag{30}$$

In our case studies, minimum wage hikes occur in two steps in consecutive years which we define as t^1 and $t^1 + 1$ so that the path of minimum wages from time $t^1 - 2$ to $t^1 + 2$ in state s is

$$w_{st^1-2} = w_{st^1-1} < w_{s,t^1} < w_{s,t^1+1} = w_{s,t^1+2}.$$

In our comparison states, denoted by ς, minimum wages are constant so that

$$w_{\varsigma t^1-2} = w_{\varsigma t^1-1} = w_{\varsigma,t^1} = w_{\varsigma,t^1+1} = w_{\varsigma,t^1+2}.$$

We use an event study approach, which allows us to visually assess the parallel trends assumption of our difference-in-difference empirical design. Denote by Y_{st} a state-level outcome in time s and D_k an indicator variable for k periods after the first-step of the minimum wage increase (so that $k = 0$ is the period of the minimum wage increase). Our base specification is:

$$Y_{ist} = a_s + a_t + \sum_{k=-3}^{3} D_k \beta_k + \epsilon_{ist}.$$

The coefficients of interest are the β_k which capture the difference in the outcome in the treated state relative to the control state.

When $\beta_k > 0$ only for $k \in \{0, 1\}$ then this specification is equivalent to the panel specifi-

cation. A

The difference in state s in outcome Y between $t^1 - 1$ and $t^2 + 2$ using equation (30) is

$$Y_{st^1+2} - Y_{st^1-1} = \sum_{j=-1}^{0} \beta_j (w_{st^1+2+j} - w_{st^1-1+j}) + (a_{t^1+2} - a_{t^1-1}) + (\epsilon_{st^1+2} - \epsilon_{st^1-1}), \quad (31)$$

and the difference in state ς is

$$Y_{\varsigma t^1+2} - Y_{\varsigma t^1-1} = \sum_{j=-1}^{0} \beta_j (w_{\varsigma t^1+2+j} - w_{\varsigma t^1-1+j}) + (a_{t^1+2} - a_{t^1-1}) + (\epsilon_{\varsigma t^1+2} - \epsilon_{\varsigma t^1-1}). \quad (32)$$

Because $w_{\varsigma t^1+2+j} = w_{\varsigma t^1-1+j}$ in the comparison states, taking the difference of (31) and (32) yields the difference-in-difference estimator

$$\begin{aligned} (Y_{st^1+2} - Y_{st^1-1}) - (Y_{\varsigma t^1+2} - Y_{\varsigma t^1-1}) &= \sum_{j=-1}^{0} \beta_j (w_{st^1+2+j} - w_{st^1-1+j}) + \epsilon^*_{st^1+2} \quad (33) \\ &= \sum_{j=-1}^{0} \beta_j (w_{st^1+1} - w_{st^1-1}) + \epsilon^*_{st^1+2} \quad (34) \end{aligned}$$

where the second line follows because the difference in the errors $\epsilon^*_{st^1+2} = [(\epsilon_{st^1+2} - \epsilon_{st^1-1}) - (\epsilon_{st^1+2} - \epsilon_{st^1-1})]$ is by assumption uncorrelated with the wage change and is in expectation 0, $w_{st^1+1} = w_{st^1+2}$ and $w_{st^1-1} = w_{st^1-2}$.

We next demonstrate the equivalence of our definitions of entry and exit across the SUSB and ES-202 data. The outcome variable in the SUSB data is rate of exit. Let in_{ist} be an indicator variable for whether establishment i, in location s at time t has positive employment at time t:

$$in_{ist} = \begin{cases} 1 & \text{if } employment_{ist} > 0 \\ 0 & \text{if } employment_{ist} = 0. \end{cases}$$

The exit rate variable in the SUSB is defined at the state-time level as the number of restaurants which exist at time $t-1$ and do not exist at time t, divided by the number of restaurants that exist at time $t-1$:

$$exitrate_{st} = \frac{\sum_i (in_{i,s,t} = 0 \ \& \ in_{i,s,t-1} = 1)}{\sum_i (in_{i,s,t-1} = 1)}. \quad (35)$$

Given a vector of variables which vary with state and time denoted by X_{st} the regression

$$exitrate_{st} = X_{st}\beta + \epsilon_{st} \tag{36}$$

implies the conditional expectation:

$$Pr[(in_{i,s,t} = 0 \ \& \ in_{i,s,t-1} = 1)|in_{i,s,t-1} \ \& \ X_{st}]. \tag{37}$$

In contrast to the SUSB data in which we estimate state-level regressions, in the ES-202 data we estimate establishment- level regressions. The exit variable in the ES-202 is an establishment-time level indicator variable for whether the restaurant exists at time $t-1$ and not time t:

$$exit_{ist} = \begin{cases} 1 & \text{if } (in_{i,s,t} = 0 in_{i,s,t-1} = 1) \\ 0 & \text{if } (in_{i,s,t} = 1 in_{i,s,t-1} = 1). \end{cases} \tag{38}$$

Given an identical set of state-time conditioning variables to the SUSB case denoted by X_{st} the regression

$$exit_{ist} = X_{st}\beta + \epsilon_{ist} \tag{39}$$

implies the conditional expectation:

$$Pr[(in_{i,s,t} = 0 \ \& \ in_{i,s,t-1} = 1)|in_{i,s,t-1}, X_{st}]. \tag{40}$$

Equations (37) and (40) are identical, which demonstrates that using the rate computed relative to last period's number of firms is the analogous outcome variable in state-level data to establishment-level variables.

Appendix E: Decomposing Changes in Employment

This appendix shows how to decompose the employment change between time $t-1$ and t into the contribution of continuing, exiting and entering firms taking into account the possibility that there might be location-specific differences in the steady state contribution of continuing, exiting and entering firms to the *level* of employment.

Let Y_{st} be employment in location s at time t. Let a_t be a time effect and a_s be a location effect. Let emp_{ist} be employment at firm i in location s at time t. A firm i belongs to the mutually exclusive set of continuing firms in time t (C_t), entering firms in time t (E_t) or exiting firms in time t (X_t) as follows

$$i \in \begin{cases} C_t & \text{if } in_{ist} = 1 \ \& \ in_{ist-1} = 1 \\ E_t & \text{if } in_{ist} = 1 \ \& \ in_{ist-1} = 0 \\ X_t & \text{if } in_{ist} = 0 \ \& \ in_{ist-1} = 1. \end{cases}$$

Then:

$$Y_{st} = \underbrace{\sum_{i \in C_t} emp_{ist}}_{Continuing} + \underbrace{\sum_{i \in E_t} emp_{ist}}_{Entering} + a_t + a_s \tag{41}$$

and

$$Y_{st} - Y_{st-1} = \underbrace{\sum_{i \in C_t} (emp_{ist} - emp_{ist-1})}_{Continuing} + \underbrace{\sum_{i \in E_t} emp_{ist}}_{Entering} - \underbrace{\sum_{i \in X_t} emp_{ist-1}}_{Exiting} + (a_t - a_{t-1}). \tag{42}$$

The location-specific component to the entering and exiting terms are not differenced out in equation (42), and so this expression cannot be used directly to measure the channels through which the minimum wage hike affects employment. To identify the contribution of the dynamic terms we need a third period of information. Rewrite equation (42) in terms of location-level rates, which Appendix D shows is equivalent to writing in terms of

establishment-level probabilities:

$$Y_{st} - Y_{st-1} = crate_{st}\Delta csize_{st} + erate_{st}esize_{st} - xrate_{st}xsize_{st} + (a_t - a_{t-1}), \tag{43}$$

where $crate_{st} = Pr(i \in C_t | in_{ist-1} = 1)$ is the continuing rate from $t-1$ to t, $\Delta csize_{st} = \frac{\sum_{i \in C_t}(emp_{ist} - emp_{ist-1})}{\sum_{i \in C_t} 1}$ is the average establishment-weighted change in size by firms producing in $t-1$ and t, $erate_{st} = \frac{\sum_i (in_{ist}=1 \ \& \ in_{ist-1}=0)}{\sum_i in_{ist-1}=1}$ is the entry rate in period t where the rate is defined relative to the number of firms in time $t-1$, $esize_{st} = \frac{\sum_{i \in E_t} emp_{ist}}{\sum_{i \in E_t} 1}$ is the average size of entrants in period t, $xrate_{st} = Pr(i \in X_t | in_{ist-1} = 1)$ is the exit rate from $t-1$ to t, and $xsize_{st} = \frac{\sum_{i \in X_t} emp_{ist-1}}{\sum_{i \in X_t} 1}$ is the average size in $t-1$ of firms that exit after $t-1$ (note the timing here—this is written this way to maintain timing consistency across terms).

We want to consider a minimum wage increase happening in period t. The time $t-1$ equivalent to equation (43):

$$Y_{st-1} - Y_{st-2} = crate_{st-1}\Delta csize_{st-1} + erate_{st-1}esize_{st-1} - xrate_{st-1}xsize_{st-1} + (a_{t-1} - a_{t-2}). \tag{44}$$

Taking the difference between (43) and (44):

$$\begin{aligned} Y_{st} - Y_{st-1} - (Y_{st-1} - Y_{st-2}) = & \underbrace{crate_{st}\Delta csize_{st} - crate_{st-1}\Delta csize_{st-1}}_{Continuing} \\ & + \underbrace{erate_{st}esize_{st} - erate_{st-1}esize_{st-1}}_{Entering} \\ & - \underbrace{[xrate_{st}xsize_{st} - xrate_{st-1}xsize_{st-1}]}_{Exiting} \\ & + (a_t - 2a_{t-1} + a_{t-2}). \end{aligned} \tag{45}$$

An identifying assumption of difference-in-difference is no state-specific pre-trends so that $Y_{st-1} - a_{t-1} = Y_{st-2} - a_{t-2}$, where we have removed the aggregate trends. This assumption

implies that

$$Y_{st} - 2Y_{st-1} + Y_{st-2} - (a_t - 2a_{t-1} + a_{t-2}) = Y_{st} - Y_{st-1} - (a_t - a_{t-1})$$
$$Y_{st} - 2Y_{st-1} + Y_{st-2} = Y_{st} - Y_{st-1} - (a_{t-1} - a_{t-2}). \tag{46}$$

Using equation (46) we can rewrite equation (45):

$$\begin{aligned} Y_{st} - Y_{st-1} = & \underbrace{crate_{st}\Delta csize_{st} - crate_{st-1}\Delta csize_{st-1}}_{Continuing} \\ & + \underbrace{erate_{st}esize_{st} - erate_{st-1}esize_{st-1}}_{Entering} \\ & - \underbrace{[xrate_{st}xsize_{st} - xrate_{st-1}xsize_{st-1}]}_{Exiting} \\ & + (a_{t-1} - a_{t-2}). \end{aligned} \tag{47}$$

The left hand side of equation (47) is the same as the left hand side of equation (42). This left hand side is estimable either by difference-in-difference or by a panel model. Similarly, each component of the right hand side is separately estimable either by difference-in-difference or by a panel model.

To convert equation (47) to elasticities, multiply both sides by

$$\frac{1}{Y_{st-1}} \frac{w_{st-1}}{w_{st} - w_{st-1}}. \tag{48}$$

Equation (48) converts the left hand side to an elasticity. The right hand side terms are not converted to elasticities by equation (48) because in steady state employment is decomposed into the contribution of continuing and entering firms as in equation (41). In steady state, the amount of exit is the same as the amount of entry and so the appropriate basis to convert the change in exit to an elasticity is the entry level. Multipling equation (47) by equation (48) and using the identity in equation (41) shows how to convert elasticities at the component

level to the overall employment elasticity:

$$\frac{Y_{st}-Y_{st-1}}{Y_{st-1}}\frac{w_{st-1}}{w_{st}-w_{st-1}} = \underbrace{\frac{crate_{st}\Delta csize_{st}-crate_{st-1}\Delta csize_{st-1}}{\sum_{i\in C_{t-1}} emp_{ist-1}}\frac{w_{st-1}}{w_{st}-w_{st-1}}}_{Continuing\ Elasticity}\underbrace{\frac{\sum_{i\in C_{t-1}} emp_{ist-1}}{Y_{st-1}}}_{Continuing\ Share}$$
$$+\underbrace{\frac{erate_{st}esize_{st}-erate_{st-1}esize_{st-1}}{\sum_{i\in E_{t-1}} emp_{ist-1}}\frac{w_{st-1}}{w_{st}-w_{st-1}}}_{Entering\ Elasticity}\underbrace{\frac{\sum_{i\in E_{t-1}} emp_{ist-1}}{Y_{st-1}}}_{Entering\ Share}$$
$$-\underbrace{\frac{[xrate_{st}xsize_{st}-xrate_{st-1}xsize_{st-1}]}{\sum_{i\in E_{t-1}} emp_{ist-1}}\frac{w_{st-1}}{w_{st}-w_{st-1}}}_{Exiting\ Elasticity}\underbrace{\frac{\sum_{i\in E_{t-1}} emp_{ist-1}}{Y_{st-1}}}_{Exiting\ Share}$$
$$+\frac{(a_{t-1}-a_{t-2})}{a_{t-1}+a_s}\frac{w_{st-1}}{w_{st}-w_{st-1}}\frac{a_{t-1}+a_s}{Y_{st-1}}. \tag{49}$$

Appendix F: Additional Tables

Table A1: Summary Statistics

	Mean	SD	N
Establishment variables:			
birth rate	0.160	0.025	525
death rate	0.156	0.018	525
expansion rate	0.298	0.024	525
contraction rate	0.287	0.020	525
Employment changes resulting from:			
births/initial employment	0.132	0.034	504
deaths/initial employment	0.114	0.028	509
expansions/initial employment	0.155	0.030	525
contractions/initial employment	0.104	0.012	525
net change/initial employment	0.069	0.041	525

Table A2: **Exit dynamics, with a permanent minimum wage increase at T**

Time	Number	Quantity	Eqn. #
$(-\infty, T)$	Δf^o	$\Delta e^{-\delta J(w^o,w^o)} f^o y_0$	16, 17
T	$f^o(J(w^o,w^o) - J(w^o,w^n))$	$\frac{e^{-\delta J(w^o,w^n)} - e^{-\delta J(w^o,w^o)}}{\delta} f^o y_0$	18, 19
$(T, T + J(w^o,w^n))$	Δf^o	$\Delta e^{-\delta J(w^o,w^n)} f^o y_0$	20, 21
$[T + J(w^o,w^n), T + J(w^n,w^n)]$	0	0	

Notes: This table summarizes results in equations (16)-(21). A Δ indicates that the pdf is bounded so that instantaneously there is no entry/exit. The Δ is a time interval.

Table A3: **Entry dynamics, with a permanent minimum wage increase at T**

Time	Number	Quantity	Eqn. #
$(-\infty, T)$	Δf^o	$\Delta f^o y_0$	22, 23
T	$\frac{\frac{e^{-\delta J(w^o,w^n)}-e^{-\delta J(w^o,w^o)}}{\delta} f^o y_0 + (Q^n - Q^o)}{y_0}$	$\frac{\frac{e^{-\delta J(w^o,w^n)}-e^{-\delta J(w^o,w^o)}}{\delta} f^o y_0 + (Q^n - Q^o)}{y_0}$	25, 24
$(T, T + J(w^o, w^n))$	$\Delta \frac{\left\{e^{-\delta J(w^o,w^n)} f^o y_0 + \delta Q^n\right\}}{y_0}$	$\Delta \left\{e^{-\delta J(w^o,w^n)} f^o y_0 + \delta Q^n\right\}$	27, 26
$[T + J(w^o, w^n), T + J(w^n, w^n)]$	$\Delta \frac{\delta Q^n}{y_0}$	$\Delta \delta Q^n$	29, 28

Notes: This table summarizes results in equations (22)-(29). A Δ indicates that the pdf is bounded so that instantaneously there is no entry/exit. The Δ is a time interval.

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