Vacancy Chains

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Abstract
Replacement hiring—recruitment that seeks to replace positions vacated by workers who quit—is a prominent feature of empirical firm dynamics. We document this phenomenon by establishing a set of novel facts: 1) many establishments exhibit no net change in employment over time, despite nontrivial quit rates; 2) higher quit rates are associated with lower degrees of net inaction; and 3) rates of inaction over net changes decay slowly by frequency (quarterly, yearly, bi-yearly etc.) suggesting that high-frequency net changes are exactly reversed at lower frequencies. A model of replacement hiring that is calibrated to match these empirical facts reveals a novel positive feedback channel through which an initial rise in vacancy posting in an expansion induces still more vacancy posting to replace employees who are poached. This vacancy chain in turn induces volatile responses of vacancies, and thereby unemployment, to cyclical shocks.

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Why are labor market stocks and flows so volatile over the business cycle? And what are the microeconomic foundations that give rise to this volatility? In this paper, we suggest answers to both of these questions.

First, we examine the microfoundations of firms’ employment decisions using rich establishment microdata from the Quarterly Census of Employment and Wages (QCEW). These reveal a striking feature of microeconomic employment dynamics: Establishments frequently report no net change in their employment, often for years at a time, despite facing substantial gross turnover in the form of quits. This suggests an important microeconomic role for replacement hiring, whereby firms go to particular lengths to refill positions vacated by workers who quit.

Second, we show that replacement hiring has profound economic implications, both for the nature of labor market frictions, as well as the volatility of labor market stocks and flows. In conventional models of labor market frictions the primary constraint to labor demand is the presence of a gross hiring cost (Mortensen and Pissarides 1994). By contrast, the prominence of replacement hiring suggests the presence of an alternative friction under which it is costly for firms to sustain net deviations from reference levels of employment, with origins in the structure of production faced by firms.

We show that this alternative view of the nature of labor market frictions considerably alters the feedback of employment decisions across firms, and thereby the volatilities of aggregate vacancies and unemployment. Conventional models of gross hiring costs capture a form of negative feedback across firms: Increased vacancy posting by other firms reduces vacancy-filling rates and raises quit rates. Both forces reduce the desired hiring of a given firm—it becomes more expensive to fill jobs, which in addition are less durable. As noted by Rogerson and Shimer (2010) this negative feedback moderates the volatility of labor market outcomes in response to aggregate shocks.

Replacement hiring, by contrast, captures a novel positive feedback channel across firms: The rise in quits induced by increased vacancy posting by other firms now raises the desired hiring of a given firm, as it seeks to replace the positions vacated by quits. This positive feedback in turn raises the volatilities of unemployment and vacancies to aggregate shocks. An initial rise in vacancy posting in an expansion induces still more vacancy posting to replace employees who are poached. This vacancy chain in turn induces volatile responses of vacancies, and thereby unemployment, to cyclical shocks. In this way, we provide answers to the two questions that motivate the paper.

The remainder of the paper is structured as follows. In section 1, we document the prominent role of replacement hiring in empirical firm dynamics. We establish four stylized facts: 1) many establishments exhibit no net change in employment over time, despite nontrivial quit rates; 2) higher quit rates are associated with lower degrees of net inaction; 3) direct measures of replacement hires account for a large fraction of total hires; and 4) rates of inaction

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2 We borrow this terminology from the early work of Akerlof, Rose and Yellen (1988) who used the idea to explain the procyclicality of job-to-job quits.
over net changes decay slowly by frequency (quarterly, yearly, bi-yearly etc.) suggesting that high-frequency net changes are exactly reversed at lower frequencies.

In section 2, we devise a model of vacancy chains that is able to account for these facts. The model builds on recently developed “large-firm” search and matching models that allow for a notion of firm size (Acemoglu and Hawkins 2014; Elsby and Michaels 2013). To capture replacement hiring, two ingredients are added. First, it allows for on-the-job search so that workers may quit to other firms. Second, it introduces into the production structure a reference employment level—that we refer to as “capacity”—from which it is costly for the firm to deviate, and which it is costly for the firm to adjust. The combination of these features induces in the model a replacement-hiring motive that mirrors that seen in the data.

Finally, in section 3 we report the results of a preliminary quantitative exploration of the model. We calibrate the model to replicate the facts on replacement hiring noted in section 1. These early results are encouraging: The model is able to match many of the moments of replacement hiring. It further suggests that the degree of replacement seen in the data induces significant positive feedback in vacancy creation. The implied volatilities of labor market stocks and flows are strikingly close to their empirical analogues.

1. Data

We use restricted-access microdata from the Quarterly Census of Employment and Wages (QCEW) that permits longitudinal linking of establishments over time from the early 1990s through to the second quarter of 2014. The data are collected by the Bureau of Labor Statistics (BLS) in concert with State Employment Security Agencies, which run state Unemployment Insurance (UI) programs, and cover all employers with employees covered by UI. Each month, firms are required to submit a count of employment and a quarterly compensation bill, which the BLS aggregates to form the QCEW. The BLS creates the Longitudinal Database of Establishments (LDE) by linking establishments over time, which permits estimation of establishment employment growth distributions that we use below.

The BLS defines monthly employment as the count of employees on an establishment’s payroll for the pay period encompassing the 12th of each month. We further follow BLS procedure by focusing on quarterly data, and defining quarterly employment as employment in the third month of each quarter. Thus, the net employment change in, for example, the first quarter of a given year is the difference between employment in the March of that year and in the December of the previous year.

The QCEW covers approximately 98 percent of employees on non-farm payrolls in the United States, and territories, and is a virtual census of non-agricultural workers in private establishments. While the data do include establishments in the public sector, we restrict analysis

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3 This aspect of the model is related to the recent work of Fujita and Nakajima (2016).

4 The count of workers includes all those receiving any pay during the pay period, including part-time workers and those on paid leave.
to privately owned establishments. Additionally, we have been granted access only to data for a subset of forty states, including Washington, DC, but excluding Florida, Illinois, Massachusetts, Michigan, Mississippi, New Hampshire, New York, Oregon, Pennsylvania, Wisconsin, and Wyoming. Finally, we restrict our data to continuing establishments, and thus abstract from births and deaths. This eliminates about 2 percent of establishments. As an example of the sample sizes involved, in the second quarter of 2014 we observe about 5 million establishments and 77 million workers.

2. Facts on replacement hiring

In this section, we describe a set of facts on the interplay between establishment-level (net) employment adjustment and gross turnover that suggests the prominence of replacement hiring. Our analysis combines the establishment-level QCEW microdata described above with publicly available data on gross turnover.

2.1 Inaction over net employment changes

Our first fact is illustrated in Figure 1, which plots the distribution of quarterly employment growth at the establishment level using the QCEW microdata. This reveals a long-recognized feature of establishment dynamics, namely that employment adjustment is marked by substantial inaction (Hamermesh 1989; Davis and Haltiwanger 1992). A large fraction of establishments—around 55 percent—maintains the exact same employment level from one quarter to the next.

An underemphasized feature of this stylized fact, however, is that inaction is expressed over net changes in employment. We highlight several important implications of this observation. First, inaction over net changes stands in contrast to the implications of standard models of employment adjustment. Since at least Nickell (1978), these have stressed the role of costs to gross employment adjustments—that is, to hiring and/or firing workers. To the extent that such models generate inaction, it will be expressed at zero gross change in employment.

Second, and relatedly, net and gross employment changes will differ due to the presence of quits. Standard estimates from the Job Openings and Labor Turnover Survey (JOLTS) suggest that the average quit rate from employers in the United States is substantial, on the order of 2

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5 We exclude establishments in public administration (NAICS industry 92), and those that are not in a classified industry (NAICS code 99). Excluding privately owned unclassified establishments eliminates approximately 225,000 employees (about 0.1% of total employment) in approximately 190,000 establishments (about 2% of total establishments) in the published, aggregate QCEW data. These restrictions are consistent with those imposed in prior literature on employment dynamics such as Foote (1998).

6 We also restrict attention to establishments that are not flagged as being a successor or predecessor of another establishment between quarters to be more confident in continuing-establishment linkages. This accounts for approximately 0.1% of establishments in the second quarter of 2014.

7 Each establishment's growth rate, $g_t$, is calculated as in Davis, Haltiwanger, and Schuh (1996), $g_t = (n_t - n_{t-1})/ [0.5 \times (n_t + n_{t-1})]$. This is equal to the log change up to a second-order approximation (around $n_t = n_{t-1}$). We then collect establishments' growth rates into bins of varying widths.
percent per month, or 6 percent per quarter. If such quits were evenly distributed across employers, standard models of gross adjustment costs would therefore imply a mass point at minus 6 percent in the employment change distribution, rather than zero.

Of course, one simple explanation for the observed inaction over net changes is that quits are not evenly distributed across establishments. For example, it could be that establishments with no change in employment are simply those “lucky” enough not to have experienced quits. However, estimates of quit rates by net employment growth taken from Davis, Faberman, and Haltiwanger’s (2006) analysis of JOLTS microdata reveal that such establishments face quit rates not much lower than the average reported above, at around 1.4 percent per month (or 4.2 percent per quarter).

The combination of such nontrivial quit rates and observed inaction over net employment changes suggests that establishments frequently hire to replace exactly those workers that quit. In what follows, we shall refer to this phenomenon as *replacement hiring*. In the remainder of this section, we explore several further implications of this notion of replacement hiring.

### 2.2 Net inaction is inversely related to quits

Our second fact is motivated by the observation that, to the extent that it is costly for establishments to replace quickly positions vacated by quits, one should discern a negative association between the incidence of quits and the degree of net inaction. That is, high-frequency employment adjustments should be observed in intervening spells following quits during which positions are replaced. In what follows, we explore this implication using industry, state and time variation in rates of inaction and the incidence of quits.

We use three measures of quit rates for this exercise. JOLTS data provide direct estimates of quit rates from employers, but cover only the period from December 2000, and include limited geographical detail. Since the majority of quits involves a direct move from one employer to another (Elsby et al. 2010), we additionally explore two estimates of employer-to-employer (E-to-E) transition rates. Fallick and Fleischman (2004) estimate monthly E-to-E rates using longitudinally linked Current Population Survey (CPS) microdata. A benefit of this measure is that it can be computed over a longer period, from 1994 onwards. Finally, data from the U.S. Census Bureau’s Longitudinal Employer-Household Dynamics (LEHD) program measure an E-to-E transition if a worker switches employer within a calendar quarter. Although the latter time aggregation problem renders the LEHD “employer-to-employer hiring rate” an inferior measure of direct job-to-job flows, it has the virtue of providing publicly available estimates by state at a quarterly frequency from 2000 to 2013. All three measures provide estimates at the broad industry level.

We combine these measures of quits with estimates of rates of inaction in net quarterly employment adjustment by industry, state and time from the QCEW microdata.

Figure 2 first explores the time series correlation between inaction and quit rates. It uses the CPS measure of the E-to-E rate, since it provides the longest time series. Two aspects of the time series provide a first indication of the negative correlation between inaction and quits implied by
replacement hiring. First, the upward trend in inaction, from around 48 percent in the mid-1990s to 55 percent in recent years, is mirrored by a downward trend in the E-to-E rate, from 2.6 percent to 1.6 percent per month. Second, the series exhibit opposite cyclical trends: the last two recessions saw prominent declines in E-to-E rates met by corresponding rises in net inaction rates. Figure 2 then explores this correlation within two-digit industries across time. All three measures of the quit rate exhibit a strong negative association with inaction rates within industry.

Finally, Table 1 explores the richer state-level information available in LEHD-based estimates of job-to-job transition rates using regressions of the form,

\[
\text{Inaction rate}_{it} = \alpha + \beta \text{E-to-E rate}_{it} + \gamma X_{it} + \epsilon_{it}. \tag{1}
\]

Here \(i\) denotes the state, \(t\) the quarter of observation, and \(X_{it}\) a vector of controls. In all specifications shown in Table 1, \(X_{it}\) includes state fixed effects. As one moves across the columns from left to right in the table, further controls are added: quarter fixed effects, then an aggregate time trend, then state-specific time trends. These controls imply that estimation of \(\beta\) is based on the association between idiosyncratic (deviations from trends) in inaction and E-to-E rates within states.

Across all specifications, the least squares estimate of \(\beta\) is negative and statistically and economically significant. For instance, from the peak prior to the 2001 recession to the peak prior to the last recession the E-to-E transition rate fell on average across states by approximately one percentage point. The estimates of \(\beta\) in Table 1 indicate that this accounts for between one quarter and one half of the rise in net inaction over the same time period.

### 2.3 Replacement hires are a large fraction of total hires

New data from the U.S. Census Bureau provide direct measures of the magnitude of replacement hires. The Quarterly Workforce Indicators (QWI), a further product of the LEHD program, define replacement hires as the difference between gross hires at an establishment and its net employment growth. For instance, if an employer expands employment in a quarter by 10 workers, but hires 12, the number of replacement hires under this definition is two.

Figure 3 plots publicly available aggregate time series from the QWI of (the annual average) of the replacement-hiring rate—that is, replacement hires as a fraction of employment from 1993Q1 through 2014Q2. For comparison, Figure 3 also illustrates the aggregate hiring rate (measured on the right axis).

Three features of Figure 3 are worth noting. First, replacement hiring comprises a large fraction of total hiring, accounting for 45 percent of all hires on average over the sample period. Second, replacement hiring is strongly procyclical, falling from a peak of about 9 percent in 2007 to close to 6 percent at its trough during the most recent recession. Finally, mirroring the path of the aggregate hiring rate, there is a modest downward trend in replacement hiring over the period: there is a peak-to-peak decline in the replacement hires rate from 10 percent to just under 9 percent from 2000 to 2007.
2.4 The slow decay of inaction by frequency of adjustment

The final stylized fact we document reveals that employers return repeatedly to the same employment levels and, strikingly, often for years at a time. This observation further underscores the magnitude of establishments’ replacement hiring motives.

To explore this fact, we utilize the panel dimension of the QCEW, which allows one to track employment in continuing establishments for many years. Specifically, Figure 4 uses this dimension of the data to plot the fraction of establishments that report the same employment level \( \tau \) quarters ahead as a function of the frequency \( \tau \). Thus, the 55-percent of establishments that report a zero net change in employment at a one quarter frequency illustrated Figure 1 is replicated in the data point at \( \tau = 1 \) in Figure 4.

Figure 4 reveals a striking result: inaction rates decay very slowly as a function of \( \tau \). To put this in perspective, as a point of reference the dotted line depicts the relationship implied if establishments’ rates of inaction were independent across \( \tau \), so that that the one-quarter inaction rate prevailed at each duration. Under this assumption, inaction decays geometrically with frequency, \( 0.55^\tau \).

In stark contrast to this hypothesis, around 40 percent of establishments report the same employment after one year (\( \tau = 4 \)). Even more remarkably, close to 30 percent of establishments report the same level of employment three years later (\( \tau = 12 \)). The counterpart probabilities under the hypothesis of independent adjustment are 9 percent after one year and essentially zero after three years.\(^8\)

The slow decay of inaction proves to be a robust feature of the microdata. To illustrate this, we subject the fact to three tests. First, rates of inaction are inversely correlated with establishment size in the data: larger establishments are less likely to report the same employment over time. It is natural to question whether the remarkable persistence of employment seen in the data is driven by small establishments. To examine this possibility, Figure 4 also reports establishment employment-weighted rates of inaction by frequency. Although size-weighting does indeed reduce estimated rates of inaction, the decay of inaction by frequency is only modestly more rapid: the three-year inaction rate is still around 40 percent of the one-quarter inaction rate.

Second, we investigate the hypothesis that the slow decay of inaction is an artefact of seasonality, for example if an employer chooses not to replace quits after its high season but returns to its high-season workforce in subsequent years. Under this hypothesis the rate of decay should be particularly low in industries where a larger share of employment fluctuations are seasonal. Figure 4 slices the data into high-, medium- and low-seasonal industries by ranking the

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\(^8\) As we shall see in Section 3, canonical dynamic labor demand models predict that it is very unlikely for an employer to adjust away from a given workforce size and then return to precisely that level in the medium run. Thus, in these models, an employer reports the same-sized workforce \( \tau \) quarters later only if it has not adjusted at all for \( \tau \) quarters.
seasonal variances of their employment. Figure 4 reveals, however, that a similar pattern emerges across all seasonal categories—inaction is prevalent and slow to decay.

Third, we examine the possibility that these patterns are a symptom of mean reversion in establishments’ labor demand. We are doubtful of this, though. To see why, suppose productivity is continuous but employment is subject to integer constraints. Then, we would expect the employer to return to the same range of employment, such that observed employment levels $τ$ quarters later are uniformly distributed around the desired non-integer level. However, we find that the distribution of employment levels $τ$ quarters later is not uniform: there is a substantial spike at the level that prevails today.

The striking persistence of the exact same establishment size suggests that employers have “reference” levels of employment to which they return routinely, and do so via replacement hiring.

3. A model of vacancy chains

The facts outlined in the previous section suggest a more nuanced view of the structure of establishment-level production. In this section we devise a model of vacancy chains that is able to replicate these stylized facts, and draws out their implications for aggregate labor market dynamics, and further confronts these implications with standard business cycle statistics.

3.1 Matching

Consider a model in which there is a mass of firms, normalized to one, and a mass of potential workers equal to the labor force, $L$. Hires in the economy are regulated by a matching technology that takes as its inputs searching workers and unfilled vacancies. Since the majority of quits transition directly from one job to another, and since our main inquiry is into the hiring behavior of firms subsequent to such quits, we allow both unemployed and, to some degree, employed workers to search for new jobs. If each of $U$ unemployed workers supplies one unit, and each of $E = L - U$ employed workers supplies $s$ units of search effort, total search effort in the economy equals $U + s(L - U)$. With $V$ unfilled vacancies, the number of new hires $M$ is given by the matching function,

$$M = M(U + s(L - U), V).$$

9 We estimate seasonal variance by regressing publicly available monthly employment data from the QCEW at the three-digit industry level on month dummies and taking the variance of the estimated coefficients. We then rank industries from lowest to highest variance and define low-seasonal industries as the lowest quartile, and high-seasonal industries as the highest quartile, of these variances. Examples of low-seasonal industries are many health care industries, and an example of a high-seasonal industry is crop production.

10 This observation mirrors the evidence from price microdata for the presence of “reference” price levels (Eichenbaum, Jaimovich and Rebelo 2011).
As is conventional, we assume that $M(\cdot, \cdot)$ exhibits constant returns to scale. With random matching, it follows that a vacancy contacts a searcher with probability $\chi(\theta) \equiv M(1/\theta, 1)$, where $\theta \equiv V/[U + s(L - U)]$ represents labor market tightness. Likewise, a worker contacts a vacancy with probability $\phi(\theta) \equiv M(1, \theta)$ per unit of search effort. As a result, an unemployed worker contacts a vacancy with probability $\phi(\theta)$, and an employed worker does so with probability $s\phi(\theta)$. Note that, although the latter represent the probabilities of contact between searchers, we will see that acceptance rates will differ, as some contacts are not consummated.

3.2 The firm’s problem

The problem faced by each firm in the economy mirrors in many respects that in related large firm search and matching models that have recently been developed (Acemoglu and Hawkins 2013; Elsby and Michaels 2013). In order for the model to be able to reproduce the significant role for replacement hiring noted in the data, however, two further ingredients are added. First, we allow for the possibility that a firm meets an employed searcher, due to on-the-job search. Second, we incorporate a notion of capacity that determines a reference level of employment from which it is costly for a firm to depart.

We formalize this idea of capacity by altering the production structure faced by firms. Labor, $n$, is used to produce output according to the production function, $y = px\tilde{F}(n; k)$. Much of the latter is standard: $p$ represents the state of aggregate labor demand (assumed constant for now), $x$ is an idiosyncratic shock that varies across firms and time according to the distribution function $G(x'|x)$, and $\tilde{F}(n; k)$ is an increasing and concave function of employment $n$. The key new ingredient is the presence of employment capacity, which we denote by $k$. To generate incentives for replacement hiring, we assume that the firm faces a discrete marginal loss of output if its employment falls below capacity. Formally, we assume that $\tilde{F}_n(k^-; k) > \tilde{F}_n(k^+; k)$. The latter is crucial for the model’s ability to generate replacement hiring since it implies there are costs of slack capacity.

We implement this idea in the following simple way:

$$y = \begin{cases} pxF(n) - c_k[k - n]^+ & \text{if } n < k, \\ pxF(k) & \text{if } n \geq k, \end{cases} \quad (3)$$

where $F_n(n) > 0$ and $F_{nn}(n) < 0$. Production is thus increasing and concave in employment, but is subject to a linear slack cost $c_k > 0$ from operating below capacity, and zero marginal returns to operating above capacity.

Of course, if the firm were free to adjust capacity without constraint, the latter frictions would be rendered redundant. For this reason, firms are assumed to face a fixed cost to changing capacity. Specifically, the firm pays a lump-sum fee $C_k$ whenever it changes capacity, $\Delta k \neq 0$.

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11 This assumption is reminiscent of “putty-clay” models of labor demand in which the degree of substitutability across factors in production is limited after a technology is implemented. See Fuss (1977), Malcomson and Prior (1979), and Manning (1994).
In a static model, the latter has a convenient implication: whenever the firm adjusts $k$, it will do so such that $n = k$, for the simple reason that there are no marginal returns to setting $n > k$, and the fact that it is costly to operate below capacity, $n < k$. Based on the results of Gertler and Leahy (2008) and Elsby and Michaels (2014), we conjecture that this static result holds as an approximation in dynamic settings (a proof is in progress). We will therefore impose the following simple law of motion for capacity,

$$k = n \text{ if } k \neq k_{-1} \text{ and } k_{-1} \text{ otherwise.}$$  \hspace{1cm} (4)

We embed this model of firm production into a search and matching model of vacancy posting. The timing of events is as follows. Each period, a firm observes the realization of its idiosyncratic shock $x$. It then chooses employment by shedding workers or posting vacancies $v$, taking into account the quit rate $\delta$ that it faces as some of its workers transition to other employers, and its ability to recruit workers from other firms expressed in the vacancy-filling rate $q$. Note that the firm’s employment choice takes into account the fixed cost of adjusting capacity, $C_k$, and in turn implies a choice of capacity $k$ under equation (4). To the extent that the firm chooses to post vacancies, $v > 0$, it must pay a convex vacancy-posting cost given by $\gamma(v)$.\footnote{Although not a standard feature of search and matching models, the presence of a convex vacancy cost is important for tractability in this environment. In a related large-firm search model with on-the-job search, Mortensen (2009) shows that a strictly linear vacancy cost implies a continuum of equilibria; the presence of quadratic costs ensures uniqueness. Numerical results for our model suggest a similar phenomenon, as do the results of the related model in Fujita and Nakajima (2016).} Finally, after employment has been determined, the firm determines wages $w$ with its workforce, and production ensues.

The firm’s problem is then characterized recursively by

$$\Pi(k_{-1}, n_{-1}, x) \equiv \max_v \{pxF(n) - c_k[k - n]^+ - w(k, n, x)n - \gamma(v) - C_k\|k \neq k_{-1}\] + \beta \int \Pi(k, n, x')dG(x'|x)\}$$ \hspace{1cm} (5)

subject to $n = (1 - \delta(k, n, x))n_{-1} + q(k, n, x)v$, and (4).

Note that the wages $w$, the quit rate $\delta$, and the vacancy-filling rate $q$ have been written as functions of the firm’s state, $(k, n, x)$. In the presence of on-the-job search, these are jointly determined. A given protocol for the determination of wages implies the values of a job in each firm from the perspective of workers, which in turn determines the mobility of workers across firms expressed in the quit and recruitment rates faced by firms. These are the subject of the next subsection, which provides a model of the joint determination of wages and turnover.

### 3.3 Wage setting and turnover

**Wage setting.** Wage determination in this environment must confront two challenges. The first, and typical of recently developed search models with a notion of firm size, is that a firm must
bargain with many workers. This multilateral dimension to wage setting arises from the presence of decreasing returns in production, $F_{nn}(n) < 0$, which implies that the surpluses generated by each of the workers in the firm are not independent of one another. The second challenge relates to how wages are determined when an employed worker meets another firm, which emerges from the presence of on-the-job search.

Our strategy for addressing both challenges is to apply the bargaining protocol proposed by Stole and Zwiebel (1996). This extends the Nash solution to a setting with decreasing returns, thereby providing a resolution to the first challenge. In a game in which a firm bargains with each of its employees in sequence, and where the strategic position of each of the workers is symmetric, Bruegemann, Gautier and Menzio (2015) show that the wage outcome corresponds to the simple Nash sharing rule over the marginal surplus.

In what follows, we will apply this marginal surplus-sharing solution to address the second challenge of wage determination in the presence of outside offers. That is, we assume that the wage offered to an employed worker contacted by an outside employer also corresponds to the multilateral-Nash bargained wage paid to that outside employer’s current employees.

A popular alternative to the latter instead proposes that, in the event a worker is contacted by an outside employer, the rival firms engage in Bertrand competition over that worker (Cahuc, Postel-Vinay and Robin, 2006). Our decision not to pursue this approach therefore merits some discussion.

A key benefit of the Nash outcome is that it is conceptually simple. By contrast, a particularly intractable implication of Bertrand competition in the context of multi-worker firms is that it is necessary to keep track of a distribution of wages within each firm that arises from heterogeneity in workers’ histories of outside offers. At the same time, we shall also see that the implications of the Nash solution are consistent with key aspects of wage growth and labor turnover. For instance, workers in the model will experience wage increases from job-to-job moves, as they move to more productive firms (Fallick, Haltiwanger, and McEntarfer 2012).

Finally, in a complete-information setting, such as the one studied here, any two firms competing over a worker know in advance which of them will prevail and hire the worker. The presence of even an arbitrarily small cost to a firm from engaging in Bertrand competition therefore would induce the losing firm to withdraw. The worker moves to the higher surplus firm, which then negotiates a wage with all of its workers under the marginal surplus-sharing protocol.  

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13 A situation in which the Nash solution might seem unnatural is when a poaching firm pays a Nash wage that is higher than the current firm’s Nash wage, but lower than the current firm’s maximum willingness to pay. But, again, note that the current firm knows that it would lose an auction over the worker. If there were any cost to their entering the auction, they would baulk.

14 We also conjecture that Bertrand competition in this setting could induce significant hold up problems in vacancy posting. A firm that posts vacancies will meet some measure of workers from a firm almost as productive as itself. If the firm engages in Bertrand competition over these workers, it will win, but will also pay the entire marginal surplus to these workers (because hiring costs are sunk ex post). Such a firm will never choose to post a costly vacancy ex ante, since it knows it will make a loss on the margin ex post.
Denoting the worker’s surplus from working in a firm with state \((k, n, x)\) by \(W(k, n, x)\) and the marginal surplus of the firm by \(J(k, n, x)\), wages solve the sharing rule
\[
(1 - \eta)J(k, n, x) = \eta W(k, n, x),
\]
where \(\eta \in [0, 1]\) denotes the workers’ bargaining power. Since wage setting occurs after hiring has been completed, it follows from the firm’s problem in (5) that the firm’s marginal surplus is given by marginal present value of a worker gross of the hiring costs,
\[
J(k, n, x) = pxF_n(n) - w(k, n, x) - w_n(k, n, x)n + \beta \int \Pi_n(k, n, x')dG(x'|x).
\]

**Turnover.** The simple surplus-sharing rule in (6) in turn implies that worker turnover takes a tractable form. Specifically, because the worker’s surplus \(W\) is proportional to the firm’s marginal surplus \(J\), it follows that \(J\) is a *sufficient statistic* for recruitment and retention from the firm’s perspective. We now show that this implies conceptually simple forms for \(\delta\) and \(q\) in the firm’s problem.

Consider first the quit rate \(\delta\). Recall that an employed worker is contacted by an outside employer with probability \(s\phi(\theta)\). Conditional on contact, she will quit in the event that the outside employer offers a higher worker surplus \(W\). Under the Nash sharing rule (6), this is equivalent to the outside firm facing a higher marginal firm’s surplus \(J\). Denoting the cumulative distribution function of marginal surpluses among *vacancy-posting* firms by \(\mathbb{J}_V(\cdot)\), the quit rate is therefore given by
\[
\delta(k, n, x) = s\phi(\theta)[1 - \mathbb{J}_V(J(k, n, x))].
\]

Now consider the vacancy-filling rate faced by the firm \(q\). Recall that, with probability \(\chi(\theta), a\) vacancy-posting firm meets a searching worker. Under random search, the firm will contact an unemployed worker with probability \(\sigma \equiv u/[u + s(1 - u)]\). Since hiring firms face a positive marginal cost to posting vacancies, their marginal surplus will be positive, and they will hire unemployed job seekers with certainty. With complementary probability, \(1 - \sigma\), the firm will contact an employed worker. Under Nash, she will be hired in the event that the firm offers a higher worker surplus, and hence marginal firm surplus, than her current firm. Denoting the cumulative distribution function of marginal surpluses among *employed workers* by \(\mathbb{J}_E(\cdot)\), the vacancy-filling rate is therefore given by
\[
q(k, n, x) = \chi(\theta)[\sigma + (1 - \sigma)\mathbb{J}_E(J(k, n, x))].
\]

With these results in hand, it is possible to see how, given a wage bargaining solution, the model can be solved. Given a conjecture for the distributions \(\mathbb{J}_V(\cdot)\) and \(\mathbb{J}_E(\cdot)\), one can solve the firm’s problem, for instance by value iteration. In this regard, note that the firm’s marginal surplus \(J(k, n, x)\) is straightforward to compute within the context of value iteration. Given a solution for a firm’s optimal labor demand policy, one can simulate productivity outcomes \(x\) and labor demand choices for many firms (in our case, hundreds of thousands). One can then
construct distributions of marginal surpluses among employed workers $J_E(\cdot)$ and the subset of vacancy-posting employers $J_V(\cdot)$, compare to the original conjectures, update, and repeat until convergence.

4. Quantitative analyses (preliminary)

We now turn to a quantitative assessment of the model. Two aspects of this assessment are preliminary. First, we focus on comparative steady-state volatilities of vacancies and unemployment in response to changes in aggregate productivity; we do not solve for the model’s transition dynamics. Second, our numerical approach builds the solution by computing the equilibrium for successively more forward-looking agents. Since we currently are in the early stages of building these solutions, the quantitative results we report are for a model in which agents are very close to myopic. Although the latter has only small effects on the implications of standard search and matching models for the volatility of labor market aggregates (see Mortensen and Nagypal 2007), a similar result is not known for our model of vacancy chains. Nonetheless, we attempt to compare all models, with and without vacancy chains, on an equal footing by keeping these aspects of the calibration constant across models.

4.1 Calibration

The majority of our calibration strategy is conventional in the class of large-firm search and matching models. We begin with these more standard features, and then turn to the parameters that govern the more novel replacement-hiring motive. Table 2 summarizes.

The time period is taken to be two weeks, which we find to be short enough to capture the high rate of worker flows in the United States.

The firm’s production function $F(n)$ and the evolution of idiosyncratic shocks $x$ are parameterized using estimates from the literature on establishment-level labor demand. Cooper, Haltiwanger, and Willis (2007, 2015) assume an isoelastic production function $F(n) = n^{\alpha}$ and estimate a returns to scale parameter $\alpha = 0.64$.

Idiosyncratic productivity $x$ is assumed to follow a geometric AR(1)

$$\ln x' = \rho_x \ln x + \varepsilon'_x, \text{ where } \varepsilon'_x \sim N(0, \sigma_x^2). \quad (10)$$

There is a large range of estimates of the parameters of this process in the literature. Abraham and White (2006) use data from the manufacturing sector and find $\rho_x = 0.68$ and $\sigma_x = 0.1$ on a quarterly basis. On the other hand, estimates from Cooper, Haltiwanger, and Willis (2015) find less persistence ($\rho_x = 0.4$) and much higher standard deviation ($\sigma_x = 0.5$). We set $\rho_x = 0.9$ and $\sigma_x = 0.12$ on a biweekly basis, which implies a quarterly persistence of 0.66 and standard deviation of the innovations of 0.3, roughly in the middle of estimates from the literature.

We assume that the matching function is of the conventional constant-returns Cobb-Douglas form, $M = \mu(u + s(1 - u))^\epsilon v^{1-\epsilon}$, where $\mu$ is matching efficiency and the matching elasticity $\epsilon$ is set to 0.5.
We then use the remainder of the standard parameters of the model to match moments of labor market stocks and flows. Since these parameters are not directly calibrated, and since the model is nonlinear, the values of all remaining parameters in principle affect all of the moments we target. Nevertheless, we provide a sense of the particular moments that inform particular parameters.

To calibrate the search intensity of the employed $s$ we target the fraction of total hires accounted for by job-to-job flows. Fallick and Fleischman (2004) estimate the latter to be close to 40 percent. Together with the rest of our calibration, we find that $s = 0.057$ matches this moment.

We calibrate vacancy-posting costs to target a vacancy rate of 3.5 percent, consistent with postwar U.S. data (from the BLS, and Barnichon 2010). Specifically, we implement the convex vacancy-posting cost using a linear-quadratic form, $\gamma(v) = \gamma_1 v + 0.5 \gamma_2 v^2$. As in Fujita and Nakajima (2016), we use a small degree of quadratic costs $\gamma_2 = 0.01$ to smooth out employment adjustment and thereby the distributions of marginal surpluses $J_V(\cdot)$ and $J_E(\cdot)$. We then set the linear cost of vacancy posting $\gamma_1$ to hit our target vacancy rate of 3.5 percent. Taken together, the linear and quadratic hiring costs amount to roughly one week’s wages.\(^{15}\)

We then use match efficiency $\mu$ to target a biweekly job-finding rate for the unemployed of 15 percent, consistent with estimates of unemployment-to-employment transition rates from the CPS of about 30 percent at a monthly frequency. Since the above calibration implies a labor market tightness of $\theta = v/[u + s(1 - u)] = 0.29$, we set match efficiency $\mu = 0.277$ so that $\phi(\theta) = \mu \theta^{1-\epsilon} = 0.15$.

Finally, as in Elsby and Michaels (2013), we vary the flow value of unemployment to a worker, which we denote $b$, to target an unemployment rate of 6.5 percent. Note that this implies a biweekly unemployment inflow rate of 1 percent. Since Hagedorn and Manovskii (2008), the magnitude of $b$ in relation to productivity has been recognized as a key determinant of the amplification of unemployment and vacancy responses to productivity shocks. We find that a value of $b$ equal to around 50 percent of output per worker matches our target unemployment rate. This value lies close to the lower range of values used in the literature.

Note that the latter calibration strategy implicitly pins down the contact rate of a posted vacancy to equal $\chi(\theta) = \mu \theta^{-\epsilon} = 0.52$ at a biweekly frequency. In the model, the latter is the vacancy-filling rate for the firm with the highest marginal surplus. This is broadly consistent with the results of Davis, Haltiwanger, and Faberman (2013) who estimate monthly vacancy-filling rates of 77 percent at the high-end of industry filling rates in JOLTS.

**Replacement-hiring parameters.** We now turn to the calibration of the more distinctive elements of the model, those that govern employment inaction and capacity adjustment and thereby replacement hiring.

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\(^{15}\) Manning (2011) reports a range of estimates from much less than one week of wages to about six weeks. Note, however, that our calculation omits any costs of hiring associated with expanding capacity, which we will see is subject to large costs.
In the model of section 2, inaction in net establishment employment growth is determined by the marginal output losses from operating below capacity $c_k$, and the costs of changing capacity $C_k$. Absent these elements, the presence of job-to-job quits in the model and vacancy-posting costs would generate inaction at zero gross employment change—that is, a discrete fraction of firms would engage neither in hiring nor firing, and would retain an employment stock equal to $(1 - \delta)n_{-1}$ rather than $n_{-1}$. Thus, the impetus for a firm to return to its prior employment level occurs if the loss of output due to slack capacity $c_k$, and the costs of adjusting capacity $C_k$, are sufficiently high relative to vacancy-posting costs $\gamma(v)$.

With this in mind, we calibrate the linear slack cost $c_k$ to target the observed net inaction rate of roughly 55 percent seen in the QCEW microdata documented in section 1. We find that this implies a slack cost equal to 25 percent of the weekly wage on average.

We then calibrate the cost of capacity adjustment $C_k$ to target the slow decay of net inaction by frequency of adjustment noted in section 1. Intuitively, for as long as a particular level of capacity remains, it will serve as an anchor for the desired level of employment, and the firm will have an incentive to return to that level routinely. In this way, the rate of capacity adjustment informs the likelihood that a firm returns to a reference employment level after several periods, and thereby the endogenous decay of employment inaction in equilibrium. We target the four-quarter employment inaction rate of 41 percent from the QCEW microdata. We find that a cost of capacity adjustment $C_k$ corresponding to 2.8 percent of output implies a quarterly capacity adjustment rate of 17 percent, and induces a four-quarter employment inaction rate of 30 percent, a little below its empirical analogue.\footnote{This aspect of the calibration is still in progress. But note that, to the extent that the four-quarter inaction is underestimated, the model will understate the amplification of vacancy responses implied by a larger capacity adjustment cost.}

Of course, our model does not incorporate capital services as a direct input into the production function. Nonetheless, there is a flavor of capital adjustment in the model’s notion of capacity adjustment, so it may be instructive to compare these capacity adjustment rates to empirical capital adjustment. Cooper and Haltiwanger (2006) estimate that capital adjustment is very uncommon, with only about 8 percent of plants engaging in investment in a year, implying a 2 percent quarterly capital inaction rate. The fact that our quarterly capacity adjustment rate of 17 percent is larger than these empirical estimates of capital adjustment suggests that capacity adjustment is more flexible than investment in structures and equipment.

4.2 Replacement hiring in the model

We now return to the facts on replacement hiring documented in section 1, and assess the ability of the model to replicate them. The first panel of Table 3 takes each of the facts in turn, and compares their empirical values with the outcomes in two versions of the model. The first is calibrated as above, and is referred to as the “Capacity” model. The second suspends the costs of
adjusting capacity, \( c_k = C_k = 0 \), and recalibrates the linear vacancy cost \( \gamma_1 \) and the flow payoff from unemployment \( b \) to match the targets for the unemployment and vacancy stocks.

The ability of the Capacity model to match the facts on replacement hiring is encouraging. It is able to match quite closely the first fact: that there is significant inaction over net employment changes despite nontrivial quit rates, even among nonadjusters. The Capacity model gets close to the net inaction rate and the quit rates. By contrast, as emphasized above, the model without capacity adjustment frictions is completely unable to generate inaction over net employment changes.

Our second fact was that the degree of inaction over net employment changes was negatively correlated with the quit rate over time, within industries, and within states. To obtain a sense of the model’s ability to capture this, we examine its steady-state response to a two-percent rise in aggregate productivity \( p \). This suggests that a one-percent rise in the quit rate is associated with a one-percent fall in the net inaction rate across steady states in the model. This value lies in the middle of the state-level empirical relationship in Table 1, but is smaller in magnitude than the time series and within-industry relationships depicted in Figure 2. Of course, the No Capacity model is unable to speak to this moment, because it fails to generate any inaction over net employment changes.

Our third fact noted that replacement hires, defined as the difference between gross hires and net employment growth at an establishment, comprise a large fraction, 45 percent, of total hires. Computing the same statistic in data generated from the Capacity model suggests that replacement hires account for 31 percent of total hires in the model. While a little short of the empirical analogue, the Capacity model substantially outperforms its No Capacity counterpart, which generates only a 3 percent replacement-hiring rate.

4.3 The volatility of unemployment and vacancies

In this section, we explore comparative steady-state responses of unemployment and vacancies to a change in aggregate productivity. In the introduction to the paper, we underscored the importance of positive feedback between the hiring decisions of firms implied by replacement hiring.

To formalize this concept, we make use of a fixed-point diagram in aggregate vacancy space, as in Figure 5. The logic of the diagram is as follows. Fix a level of unemployment and the calibration of the model outlined above. Each level of aggregate vacancies along the horizontal axis will imply contact rates for vacancies and for workers: as aggregate vacancies rise, a firm’s vacancies will contact searching workers less frequently, and its employees will receive more outside offers. Given these contact rates, firms make their optimal vacancy-posting decisions. We plot the aggregate vacancies implied by these optimal vacancy decisions on the vertical axis. Equilibrium vacancies are thus a fixed point of this map (for a given level of unemployment, to which we shall return shortly).

Figure 5 plots this map for each of the two calibrated models—the “Capacity” model that captures the replacement hiring moments of section 1; and the “No Capacity” model that
suspends this motive. The slope of the map indicates the degree of feedback in the model, that is, the degree to which vacancy posting by other firms raises a given firm’s vacancy creation.

Consider first the No Capacity model. Here the map is only very mildly downward-sloping: vacancy posting decisions across firms are almost independent of one another. Intuitively, this is the outcome of two opposing forces. On one hand, increased aggregate vacancies lower vacancy contact rates and raise employee quit rates. These lower desired hiring in the No Capacity model, since it renders hiring more costly, and jobs less durable. On the other hand, for a given level of desired hiring, a lower vacancy contact rate requires a firm to post more vacancies to achieve its desired level of hires. It turns out that these two forces nearly offset, with the former effect slightly stronger in the calibration of the No Capacity model, yielding the slightly downward-sloped map.

Now consider the Capacity model. This implies that the degree of replacement hiring seen in the data is consistent with significant positive feedback between the vacancy decisions of firms—the vacancy map is positively inclined. The reason is that the first-order effect of higher aggregate vacancies in this model is to raise the quit rate from firms, which induces more vacancy posting as firms seek to replace positions vacated by quits.

Figure 5 then reveals how these differing feedback channels in turn shape the volatility of the vacancy response to a change in aggregate productivity $p$. Since a rise in $p$ shifts up the vacancy locus in Figure 5, the equilibrium response of vacancies is increasing in the degree of positive feedback, and indicated by the slope of the vacancy locus. Intuitively, initial rises in vacancies driven by aggregate expansions set off a chain reaction of further vacancy posting as firms increasingly poach workers from each other, amplifying the equilibrium response of aggregate vacancies.

Up to now, we have been considering the response of vacancies to a change in aggregate productivity, after unemployment has fully adjusted to its new equilibrium. The determination of the latter can be considered in two stages: one that involves a rise in vacancies holding unemployment fixed and one that involves another loop that maps the rise in vacancies to declines in unemployment. This additional loop is depicted in the decomposition in Figure 6. This reveals that the positive feedback that induces volatile equilibrium vacancy responses also amplifies the feedback effect from unemployment back onto vacancies. The intuition is analogous: As unemployment declines, the labor market tightens still further, and quit rates (and hence poaching) rises still more. This induces yet more replacement hiring and further vacancies in the Capacity model. To see this in Figure 6, observe that the vacancy locus following the productivity shift shifts upward still further after unemployment adjusts. By the same token, this further feedback mechanism is approximately neutral in the No Capacity model.

The upshot of this mechanism is summarized in the bottom panel of Table 3. This shows that the response of vacancies, unemployment, and labor market flows with respect to a
productivity shock across steady states are strikingly similar to their empirical counterparts in the Capacity model. By contrast, the No Capacity case generates far too small a vacancy response.\textsuperscript{17} 

\textsuperscript{17} In addition, the No Capacity model overstates the response of unemployment inflows to a change in aggregate productivity. We are exploring the origins of this result.
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Figure 1. Inaction over net employment changes
Figure 2. Net inaction is inversely related to quits

A. Aggregate time series

B. Within-industry changes (CPS E-to-E rate)

C. Within-industry changes (JOLTS quit rate)

D. Within-industry changes (LEHD E-to-E rate)
Figure 3. Direct measures of replacement hiring
Figure 4. The slow decay of inaction by frequency of adjustment

A. Inaction by frequency

B. Inaction by frequency and industry seasonality
Figure 5. The response of equilibrium vacancies to a change in aggregate productivity
Figure 6. Decomposition of the response of equilibrium vacancies to a change in aggregate productivity

A. Capacity model

B. No Capacity model
Table 1. The state-level relationship between inaction and job-to-job transition rates (LEHD)

| Dependent variable: State-level net inaction rate |
|--------------------------------------------------|
| E-to-E rate (LEHD) | \(-2.325^{***}\) | \(-1.541^{***}\) | \(-1.296^{***}\) | \(-1.541^{***}\) | \(-1.135^{***}\) | \(-0.783^{***}\) |
|                    | \((0.105)\)       | \((0.446)\)       | \((0.170)\)       | \((0.446)\)       | \((0.0923)\)       | \((0.212)\)       |
| Constant           | \(0.578^{***}\)   | \(0.529^{***}\)   | \(0.380^{***}\)   | \(0.409^{***}\)   | \(0.367^{***}\)   | \(0.338^{***}\)   |
|                    | \((0.00366)\)     | \((0.0216)\)      | \((0.0179)\)      | \((0.0406)\)      | \((0.00639)\)      | \((0.0240)\)      |
| Observations       | 2,071              | 2,071              | 2,071              | 2,071              | 2,071              | 2,071              |
| R-squared          | 0.444              | 0.797              | 0.771              | 0.797              | 0.840              | 0.867              |
| Number of states   | 40                 | 40                 | 40                 | 40                 | 40                 | 40                 |
| Quarter FE         | No                 | Yes                | No                 | Yes                | No                 | Yes                |
| Time trend         | No                 | No                 | Yes                | Yes                | Yes                | Yes                |
| State time trend   | No                 | No                 | No                 | No                 | Yes                | Yes                |

Notes: Regressions are weighted by average employment in the state. Standard errors in parentheses are clustered at the state level. *** p<0.01, ** p<0.05, * p<0.1.
Table 2. Calibrated parameters

| Parameter | Meaning                           | Value  | Reason                                           |
|-----------|-----------------------------------|--------|-------------------------------------------------|
| $\beta$   | Discount factor                   | 0.67   | In progress                                      |
| $\alpha$  | Returns to scale                  | 0.64   | Cooper et al. (2007, 2015)                       |
| $\rho_x$  | Persistence of shocks             | 0.9    | Cooper et al. (2015), Abraham and White (2006)  |
| $\sigma_x$| Std. dev. of shocks               | 0.12   | Cooper et al. (2015), Abraham and White (2006)  |
| $\epsilon$| Matching elasticity               | 0.5    | Petrongolo and Pissarides (2000)                 |
| $\eta$    | Bargaining power                  | 0.5    | Equal to matching elasticity                     |
| $s$       | Search intensity of employed      | 0.057  | 40 percent of hires from employment             |
| $\gamma_1$| Linear vacancy cost               | 0.0456 | Vacancy rate = 0.0345, Barnichon (2010)         |
| $\gamma_2$| Quadratic vacancy cost            | 0.01   | Mortensen (2009)                                |
| $\mu$     | Matching efficiency               | 0.277  | Job-finding rate of the unemployed = 0.15        |
| $b$       | Flow unemployment payoff          | 0.225  | Inflow rate = 0.01, Unemployment rate = 0.065    |
| $c_k$     | Slack cost                        | 0.0832 | One-quarter inaction rate = 0.55                 |
| $C_k$     | Capacity adjustment cost          | 0.125  | Four-quarter inaction rate = 0.41                |
Table 3. Model-generated moments and comparative statics

| Fact | Moments | Data | Capacity | No Capacity |
|------|---------|------|----------|-------------|
| 1    | One-quarter inaction rate | 0.55 | 0.57 | 0 |
| 1    | Quits as share of employment (monthly) | 0.017 | 0.013 | 0.016 |
| 1    | Quit rate among nonadjusters (monthly) | 0.014 | 0.012 | — |
| 2    | Slope of inaction-quit rate relationship | [-.8,-2.3] | -1.0 | — |
| 3    | Replacement hires as a share of total hires | 0.45 | 0.31 | 0.03 |
| 4    | Four-quarter inaction rate | 0.41 | 0.30 | 0 |
|      | E-to-E flows as a share of total hires | 0.38 | 0.38 | 0.44 |
|      | One-quarter capacity-inaction rate | — | 0.83 | — |
|      | Vacancy-filling rate (monthly) | 0.74 | 0.71 | 0.75 |
|      | \(\Delta \ln \text{vacancies} / \Delta \ln p\) | 10.1 | 9.9 | 1.8 |
|      | \(\Delta \ln \text{unemployment} / \Delta \ln p\) | -9.5 | -11.1 | -10.6 |
|      | \(\Delta \ln \text{job-finding rate} / \Delta \ln p\) | 5.9 | 7.7 | 4.6 |
|      | \(\Delta \ln \text{inflow rate} / \Delta \ln p\) | -3.8 | -4.7 | -7.6 |
|      | \(\Delta \ln \text{vacancy-unemployment ratio} / \Delta \ln p\) | 19.1 | 21.0 | 12.5 |
|      | \(\Delta \ln \text{average wages} / \Delta \ln \text{employment}\) | \(\approx 1\) | 0.77 | 0.74 |

Notes: The “Capacity” model is calibrated as in Table 2. The “No Capacity” model is recalibrated to hit unemployment and vacancies by adjusting vacancy-posting costs and the flow payoff from unemployment. Elasticities are inferred from a two-percent comparative steady-state change in aggregate productivity. A “—” indicates that the moment is not available.

Data sources: Monthly quit rates, quit rates among nonadjusters, and vacancy-filling rates are taken from Davis, Faberman, and Haltiwanger (2006, 2013). Inaction rates, and slope of inaction-quit relationship are taken from authors’ analysis of QCEW microdata. The share of hires from job-to-job changes is taken from Fallick and Fleischman (2004). The replacement-hiring rate is the number of replacement hires in excess of net creation divided total new hires taken from the QWI. The elasticity of average wages with respect to employment is taken from Solon, Barsky and Parker (1994) and Elsby, Shin and Solon (2016). Elasticities of vacancies, unemployment, job-finding and unemployment inflow rates are taken from Shimer (2005).