On-the-job Search and the Productivity-Wage Gap *

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Abstract

We examine how worker and firm on-the-job search have differential impacts on the productivity-wage gap. While an increase in both worker and firm on-the-job search raise productivity, they have opposing effects on wages. Increased worker on-the-job search raises workers' outside options, allowing them to demand higher wages. Increased firm on-the-job search improves firms' bargaining position relative to workers' by raising job insecurity and the wedge between hiring and meeting rates, allowing firms to pass-through a smaller share of productivity to wages and enlarging the productivity-wage gap. Quantitatively, the model accounts for about a quarter of the observed divergence in the US productivity-wage gap between 1990 and 2017.

Keywords: On-the-job search, Replacement hiring, Productivity-wage gap, Unemployment, Labor share
JEL Codes: E24, J63, J64

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1 Introduction

The US economy observed an increasing divergence between labor productivity and wages over the last two decades preceding COVID-19. Figure 1 shows that prior to 2000, real compensation per hour grew at roughly the same rate as real output per hour, i.e. labor productivity.[1] Post 2000, however, there emerged a divergence between labor productivity and wage compensation. This gap between labor productivity and wage compensation - which we term the productivity-wage gap - grew. This widening occurred even as the unemployment rate reached new lows in the aftermath of the Great Recession and the quits rate surpassed its pre-recession level, suggesting that the increase in the gap was not due to slack labor markets. Given this backdrop, we ask instead how the incidence of firm on-the-job search (OJS) and its impact on outside options can affect the productivity-wage gap.

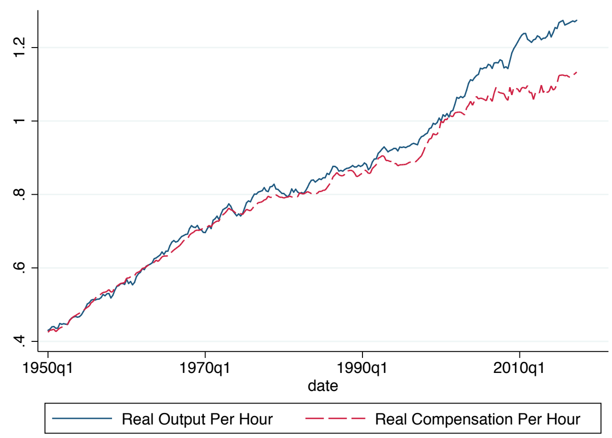


Figure 1: Labor productivity and real hourly compensation

Notes: (i) Data on Current Output Per Hour and Current Compensation per Hour comes from the U.S. Bureau of Labor Statistics Productivity and Costs database. We deflate both measures using the consumer price index (CPI). We normalize the deflated measures to be 1 in 2000Q1.

The way firm OJS manifests itself is through replacement hiring - firms who seek higher quality applicants replace current workers with better workers. While we do not directly observe firm OJS in data, we do see measures of replacement hiring, which are defined by the Census as hires that continue into the next period in excess of non-negative net employment change.[2] The widening of the productivity wage gap has been accompanied by an upward trend in the fraction of total hires that are replacement hires.[3] Using data from the Quarterly Workforce Indicators (QWI), Figure 2a shows that replacement hires as a fraction of total hires has increased from about 33% in the early 1990s to a high

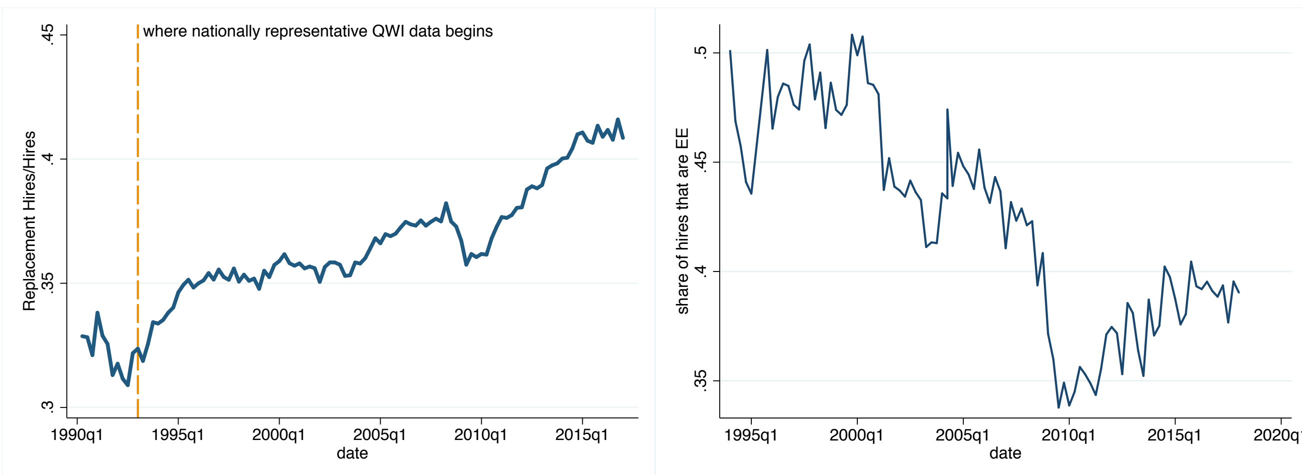
[1]To calculate real compensation per hour and real output per hour, we take current output per hour and current compensation per hour and deflate both measures using the CPI. Note that by using a common price index, the divergence in the productivity and wages stems not a difference in price deflators. Compensation includes direct payments to labor, e.g. wages, salaries, etc, and also includes wage supplements, e.g. private pension, health plans, etc.

[2]See Section 2 for more details. All definitions are taken from https://lehd.ces.census.gov/doc/QWI_101.pdf.

[3]It is important to note that the increased share of replacement hires is not inconsistent with declining labor mobility and declining trends in job creation. In fact, as a fraction of average total employed, the replacement hiring *rate* has been declining over time. Figure 8a in Appendix A shows that the hiring rate has fallen faster than the replacement hiring rate. The sharper decline in total hires relative to replacement hires implies that replacement hiring is increasingly becoming a more important share of total hiring.

of about 41% in 2017.[4] Notably, the rise in the replacement hiring share is broad-based and not driven by a few industries, or by larger firms.[5]

The time aggregation at a quarterly frequency implies that replacement hires don't just record instances of firm OJS; replacement hires are also recorded whenever a firm re-fills a vacated position, which could occur whenever an employed worker quits for a better job, necessitating the firm to hire a replacement. However, Figure 2b shows that employment-to-employment transitions (EE hires) as a fraction of total hires trended downwards during this period of time, suggesting that EE hires are unlikely to account for the increase in the share of replacement hires. In fact, in Section 2, we show that not all of replacement hiring in the data can be accounted for by quits. The rise in the replacement hiring share amid the decline in the ratio of EE hires to total hires suggests that firm on-the-job search (OJS) may be an overlooked channel which is growing in importance.



(a) Replacement hires as a share of total hires

(b) EE hires/total hires

Figure 2: Trends in replacement hiring vs. worker job-to-job transitions

Notes: (i) The replacement hiring share is the ratio of replacement hires to hires. We formalize this definition in Section 2. (ii) The EE hires share is the number of employed individuals who moved to a new employer divided by hires. This measure is calculated using data from the Current Population Survey (CPS). To capture the numerator of this measure, we employ the same techniques as in Fallick and Fleischman (2004).

We view firm OJS as a natural starting point for understanding how a wider productivity-wage gap could emerge. To this end, we build a model that features OJS by both workers and firms. In our model, search is random and firms pay a fixed cost to create a new vacancy. A vacancy in our model is synonymous with a job position being created. A vacancy or job position is long-lived and is not destroyed instantaneously. Rather, a vacancy continues to exist even if the firm fails to fill it immediately. Further, firms whose job positions have been filled can continue to meet applicants i.e, firms can conduct on-the-job search, so long as the job position has not been destroyed. When firms search on-the-job, they seek applicants who are better matches than their current workers, and who can bring higher profits to the firm. In the same vein, workers in our model also conduct on-the-job search so as to meet vacancies who are better matches than their current firms. In their efforts to match with

[4] Information collected on replacement hiring as recorded in the QWI only begins from the 1990s.

[5] Appendix A shows that the rise in the share of replacement hiring is broad-based, occurring across both industries and across firms of different ages and sizes, Appendix A also shows that the results from a shift-share analysis suggest that the "within" component accounts for the bulk of the increase in the replacement hiring share.

higher productivity applicants and firms, both firm and worker OJS raise labor productivity. Thus, an increased incidence of either worker or firm OJS is associated with higher labor productivity.

What matters for the emergence of a productivity-wage gap is the *extent* to which gains in productivity are passed-through to wages. If a smaller share of the increase in productivity is passed through to wages, then wages increase by less than productivity, resulting in a widening of the productivity-wage gap. Worker and firm OJS have opposite implications for the pass-through of productivity to wages. A greater ease with which a worker can search on-the-job raises the worker's effective outside option, which improves their bargaining position relative to that of the firm, allowing them to demand a higher share of productivity to be passed-through to wages.

A greater ease with which firms can search on-the-job does the opposite. Using our theoretical framework, we uncover three channels through which firm OJS depresses workers' effective outside options relative to that of firms and show how this in turn lowers the pass-through from productivity to wages. First, long-lived vacancies imply that firms have a positive option value from holding a vacancy. This positive option value raises a firm's effective outside option, allowing it to keep wages low when bargaining with the worker. Second, firms' ability to conduct OJS raises the rate at which workers endogenously separate into unemployment, i.e., workers now face higher *job insecurity.* Increased job insecurity reduces employment spells and the worker's effective outside option, further allowing firms to pass-through a smaller share of productivity to wages. Finally, when firms can search on-the-job, the composition of vacancies comprises of both unfilled and filled vacancies. For an unemployed applicant to be hired at this latter type of vacancy, their productivity must be higher than that of the firm's incumbent worker. Thus, relative to meeting an unfilled vacancy, unemployed job-seekers must pass a higher bar before they are hired. This drives a larger wedge between hiring and meeting rates - lowering *measured matching efficiency* and in turn diminishing workers' effective outside options and their ability to capture a larger share of productivity. All three forces promote a wider productivity-wage gap.

To investigate the impact of firm vs. worker OJS on the productivity-wage gap, we conduct two separate exercises. First, we present some comparative statics. We analytically show that an increase in either the worker's or firm's ability to conduct on-the-job search raises average productivity, ceteris paribus. Intuitively, when both firms and workers have a higher ease of searching on-the-job, they can re-match more easily into higher productivity matches, causing average labor productivity to increase. The extent to which productivity is passed-through to wages, however, depends on the relative ease with which workers or firms can search on-the-job. We show that when firms are better able to search on-the-job, the worker's effective outside option is reduced relative to the firm's option value. This change in the worker's effective outside option allows firms to pass on a smaller share of productivity to wages, widening the productivity-wage gap. Our comparative static exercises highlight that a higher ease of worker OJS serves to narrow the productivity-wage gap while a higher ease of firm OJS does the opposite. The size of the productivity-wage gap thus depends on how easily firms vs. workers can search on-the-job. Empirically, we find that industries with higher replacement hiring shares observe larger productivity-wage gaps, a result that from the lens of our model would suggest is because of the extent of firm on-the-job search.

Second, we calibrate the model to match labor market flows in the US across two time periods: pre- and post 2000. We specifically target the ratio of layoffs to quits as well as the EE transition rate to pin down parameters relating to firm OJS and worker OJS. We use the year 2000 as our cut-off as the divergence in the productivity-wage gap became more severe post 2000. In conducting this exercise, we examine if our calibrated model can replicate the observed wider productivity-wage gap. Our model predicts that across the two time periods, the ease at which firms searched on the job improved while worker OJS declined. This rise in firm OJS and decline in worker OJS causes our model-generated productivity-wage gap to rise by about 2 percent, a quarter of the empirical 8% increase in the productivity-wage gap between the period from 1990-2000 and the post 2000 period.[6] The widening in the productivity-wage gap is accompanied by a rise in job insecurity, lower measured matching efficiency, and higher firms' effective outside options, all of which are factors that depress the worker's bargaining position relative to the firm. Consequently, while labor productivity rises with the firm's increased ability to conduct OJS, average wages are lower as a smaller share of productivity gains is passed through to wages with the decline in workers' effective outside options.

Related Literature Our paper contributes to the growing literature on the impact of replacement hiring. Two papers are closely related to ours. Both Mercan and Schoefer (2020) and Elsby et al. (2019) focus on the business cycle properties of vacancy posting and examine how replacement hiring and quits by workers necessitates a firm to re-fill a position. Importantly, the two aforementioned papers focus on worker OJS while we examine the implications of OJS by firms and workers on the productivity-wage gap. Separately, Menzio and Moen (2010) examine replacement hiring in the context that firms seek to insure workers against income fluctuations but cannot commit to not replacing current workers in a downturn with cheaper new hires. While their paper is concerned with characterizing the efficient wage contract, we examine instead, the implications firm on-the-job search has on wages in the absence of any aggregate productivity shocks. In related work, Kiyotaki and Lagos (2007) study a random search model which features both replacement hiring and worker on-the-job search. They examine the extent to which the decentralized economy can implement the planner's outcome when workers and firm both engage in Bertrand competition in terms of life-time utility offers. Importantly, their paper abstracts from wages while our paper is primarily concerned with how worker vs. firm on-the-job search can affect the productivity-wage gap. As such, our paper takes a stance on how wages are determined and in doing so, highlights how worker vs. firm on-the-job search have contrasting implications for pass-through and the gap between productivity and wages.

Although we study how worker vs. firm OJS can affect the productivity-wage gap, our paper also has implications for the labor share. Intuitively, the divergence in labor productivity and compensation implies that a smaller share of total output accrues to labor. Karabarbounis and Neiman (2013) document that the labor share has declined across countries and argue that capital deepening is the primary factor behind this decline. Elsby et al. (2013) conduct a comprehensive study and find a strong negative relationship between import exposure and the labor share at the industry level. We add to this debate by highlighting a separate channel that can give rise to a lower labor share. When firms are more able to do OJS relative to workers, the higher option value of firms relative to workers allows firms

[6] We measure the productivity-wage gap as the ratio of labor productivity to mean compensation. Since the our data for replacement hiring only begins in the 1990s, we only calculate the change in the productivity-wage gap between the periods 1990-2000 and post 2000.

to pass-through a smaller share of productivity to wages. This results in a wider productivity-wage gap and consequently, a lower labor share.

Recent work by Autor et al. (2020) and Azar et al. (2022) suggest that product market concentration is associated with labor market concentration. When there are a few firms that dominate the product and labor market, firms internalize that they have market power and offer lower wages. Using a model of oligopsony, Berger et al. (2022) estimate the extent of firm market power and its implied impact on the labor share. Importantly, they find that local labor market concentration has actually declined over the past 35 years, suggesting that the change in local labor market concentration would have implied an increase in the labor share and a greater pass-through of productivity to wages. Relative to these papers, we offer an alternative view of firm labor market power. Our notion of firm labor market power rests not on market concentration, but instead relates to the firm's option value and its ability to conduct OJS. Our model suggests that so long as firms have a higher ease of OJS relative to workers, the pass-through of productivity to wages is smaller. Our model is distinct from models of monosopny, where firms internalize how their hiring and wage setting decisions affect labor market outcomes. In our model, firms are small and take labor market conditions as given. Instead, it is the positive option value of firms and their ability to search on-the-job that endogenously leads to a weakening in workers' bargaining position and to a smaller pass-thorough of productivity to wages.

Our paper is also related to the recent literature on phantom vacancies. Cheron and Decreuse (2017) and Albrecht et al. (2023) argue that phantoms are vacancies that have already found a match and cannot generate any more new hires. The existence of phantoms lowers matching efficiency as unemployed job-seekers cannot convert a meeting with a phantom into a hire. We offer an alternative view: matched firms with unexpired vacancies can still generate hires. An unemployed job applicant who contacts a recruiting matched firm, however, must surpass the productivity of the incumbent worker before she is hired. As such, these long-lived vacancies which allow firms to conduct OJS also lowers measured matching efficiency. Recent work using online vacancy job board data by Davis and de la Parra (2017) suggests that a non-trivial portion of job postings are "long-duration" postings which are continuously on the look-out for new applicants, giving support to our supposition that vacancies are long-lived and can re-match with multiple workers.

Finally, our paper is also related to the literature on long-lived vacancies. Fujita and Ramey (2007) and Haefke and Reiter (2020) consider models where job positions are long-lived and firms do not shut down immediately upon worker separation. Both of these papers demonstrate that the inclusion of long-lived vacancies in a labor search model can better replicate labor market flows in the data. Firms with unexpired job positions in these models only re-hire new workers when they are separated from their current worker. As such, these models do not address the issue of firm OJS and its ramifications for the productivity-wage gap.

The rest of this paper is organized as follows. Section 2 discusses the data on replacement hiring. Section 3 introduces the model. Section 4 outlines our comparative static exercises and highlights how worker vs. firm OJS affects wages and productivity. Section 5 presents our quantitative analysis while Section 6 contains a brief discussion about some assumptions of our model. Finally, Section 7 concludes.

2 Data

Our goal is to shed light on how firm OJS can affect the productivity-wage gap. Given the datasets available to us, we do not have direct evidence on firm OJS. Since firm OJS manifests itself through replacement hires, we instead use information on the replacement hiring share to examine the impact of firm OJS on the productivity-wage gap. Because replacement hires can occur both for the purposes of refilling a vacant position that a worker quit or for the purposes of firm OJS, we first outline how quits do not account for all of replacement hiring. Having documented that replacement hires can occur for both worker and firm OJS reasons, we use the implications of our model to test how the direction of the relationship between the productivity-wage gap with the replacement hiring share depends on whether firm or worker OJS is more prevalent. We present our findings in the following order: Section 2.1 first defines how replacement hiring is measured while Section 2.2 discusses our results on the *sign* of the relationship between the productivity-wage gap and replacement hiring.

2.1 Measuring Replacement Hiring

Building on the underlying Longitudinal Employer Household Dynamics (LEHD) linked employee-employer database, the QWI provides information at the state, industry and national level on the number of hires, separations, job gains and losses as well as average earnings. The QWI provides information at the *establishment level*. Thus, while we use the term 'firm' in this paper because we are interested in the consequences of firm OJS on the productivity-wage gap, it should be recognized that in the data, the unit of observation is at the establishment level. Further, the measures that we use are the publicly available aggregated measures derived from the underlying micro-data on establishments.

The QWI defines job gains at a firm as the non-negative change in employment within a quarter:

$$\text{Job Gains } = \max\left\{\text{Emp}_t^{\text{end}} - \text{Emp}_t^{\text{beginning}}, 0\right\}$$

In contrast, hires at a firm in quarter t is defined at the total number of new employees at a establishment who did not have earnings in period $t-1$ but who reported earnings at that firm in period t. Hires are recorded as the gross inflows into a firm, while job gains are recorded as the non-negative net employment change at the firm. Replacement hires are defined in the QWI as the hires that continue into the next quarter *in excess* of job gains at a firm. Using data from the QWI, we calculate the replacement hiring share as the fraction of hires that are replacement hires, i.e.

$$\text{Replacement Hiring Share} = \frac{\text{Replacement Hires}}{\text{Hires}} = \frac{\text{Hires At End - Job Gains}}{\text{Hires}}$$

where "Hires At End" refer to hires that continue into the next quarter, i.e. an individual who records earnings in periods t and $t+1$ but not in period $t-1$. "Hires At End" are a sub-set of "Hires". The latter includes both hires that continue into the next quarter and individuals hired only for that particular quarter, i.e. the individual only has a record of earnings at time t. By definition, when there are zero hires that continue into the next quarter, there would be zero replacement hires recorded.[7] We

[7]This implies that the level of replacement hires is bounded below by zero. Thus, if a firm contracts and only observed

use this definition of replacement hiring share in Figure 2a.[8] Supplementing the infomation contained in Figure 2a, Appendix A shows that the rise in the share of replacement hiring is broad-based, and not just concentrated within a few industries, or amongst old and larger firms only.

It is important to note that because replacement hires capture the hires that continue into next quarter in excess of job gains, the replacement hiring share is *not* equivalent to the ratio of separations to hires. This is because only a subset of separations are associated with replacement hires.[9] Thus while all replacement hires are associated with separations, not all separations are replacement hires.

Finally, another recent paper (Elsby et al., 2019) also provides an alternative measure of replacement hiring. Specifically, Elsby et al. (2019) define it as the minimum of gross hires and quits at a firm. This measure of replacement hires is not the same as the definition in the QWI but is consistent with the model presented in Elsby et al. (2019) which views replacement hires as being conducted whenever a worker quits. We, however, strictly follow the definition of replacement hires as provided by the QWI. For our purposes, this definition is more appropriate since it captures replacement hires that are conducted not just when a worker quits but also when a firm conducts OJS. To see this, consider a firm which had zero workers quit. The firm, however, decided to replace 1 worker with a higher productivity applicant. In this example, there is 1 hire, 1 fire and hence 1 replacement hire. Using a measure of replacement hires as in Elsby et al. (2019), which is the minimum of gross hires and quits, however, would suggest that there are zero replacement hires when there are zero quits. As such, the QWI's definition of replacement hires better captures replacement hiring that occurs for both firm OJS reasons as well as for the purpose of refilling vacated positions. In what follows, we show that quits cannot account for all replacement hires.

When do replacement hires occur? Because a replacement hire always coincides with a separation, it is useful to distinguish between the different types of separations that can lead to a replacement hire. Using the JOLTS micro-data, Elsby et al. (2019) focus on firms who have the same employment level τ periods later and measure the cumulative hires rate (solid blue line) and cumulative quits rate (dashed-red line) at such firms. Importantly, since these firms observe zero net employment change, the cumulative hires is equal to cumulative separations and these cumulative hires represent replacement hires. While quits do affect the amount of replacement hiring, Figure 3a from Elsby et al. (2019) shows that not all replacement hires stem from refilling positions vacated by workers who quit. Rather,

separations, the QWI records zero rather than "negative" replacement hires at this firm.

[8] Our finding that the replacement hiring share rose over time is robust even if we use a different measure of the replacement hiring share. Specifically, if we only consider replacement hires as a fraction of all hires that continue into next quarter (as opposed to all hires that include individuals who were hired in a quarter but who did not stay on until the next quarter), this alternative replacement hiring share rose from 0.55 in the 1990s to about 0.60 in 2017.

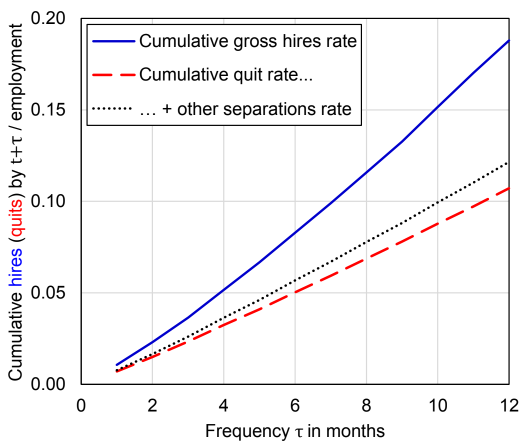
[9] The following accounting identity from the QWI makes clear that replacement hires is not equal to total separations observed in the data:

$$\text{Hires} - \text{Separations} = \text{Job Gains} - \text{Job Losses}$$

Since replacement hires are only measured as the hires in excess of job gains which only counts non-negative net-employment change, replacement hires are not equal to total separations. To see this, consider the example of a firm who started the period with 1 worker. Suppose that worker left the firm and the firm hired a new worker to re-fill its vacated position. In addition, this new worker left the firm before the end of the period. In this example, the firm experienced a net employment change of -1, stemming from the 2 separations and 1 hire. Because that hire did not continue into the next period, the replacement hiring share at this particular firm would be equal to 0 since no hire continued into the next period. However, the ratio of separations to hires in this example would be equal to 2.

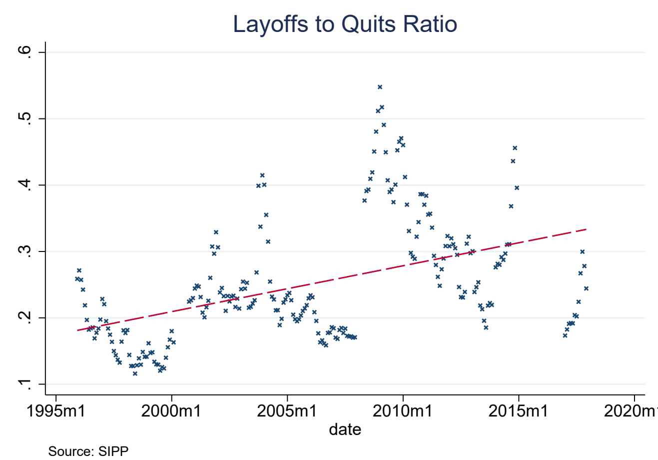
Figure 3a reveals that a non-trivial wedge exists between the cumulative hires rate and cumulative quits rates (plus other separations)[10], suggesting that a significant portion of replacement hiring also occurs alongside the event of a layoff. Moreover, Elsby et al. (2019) show that the replacement hiring share as captured by quits is relatively constant. This is suggestive that the growth in the replacement hiring share (highlighted in Figure 2a) is driven by factors other than quits. These two facts suggest that a non-trivial share of replacement hiring are triggered by layoffs. Our paper, by focusing on firm OJS, precisely captures how this phenomenon can occur.

While we cannot directly distinguish whether a replacement hire occurred because of a quit or because of a layoff in the QWI, the Survey of Income and Program Participation (SIPP) provides information on the reason why a worker stopped working at his previous job, and distinguishes whether the cessation of work occurred because of a layoff or because of a quit.[11] Further, the SIPP distinguishes whether the quit was to a new job or to non-employment. Figure 3b shows that since the mid-1990s, the ratio of layoffs to quits-into-new-jobs has been increasing over the same period as when the replacement hiring share was rising and the rate of EE transitions was declining. Overall, this suggests that layoffs may account for a non-trivial share of replacement hiring.



Source: Elsby et al. (2019)

(a) Quits do not account for all of replacement hiring



(b) Layoff -to-quits ratio

Figure 3: Both Layoffs And Quits Affect Replacement Hiring

2.2 Relationship between productivity-wage gap and on-the-job search

Next, we investigate the relationship between OJS and the productivity-wage gap. Because we do not have direct measures of firm OJS, we instead focus on the relationship between the productivity-wage gap and replacement hiring share. As aforementioned, our model implies that there is a negative relationship between the two if worker OJS is the primary driver of replacement hiring, as workers' outside options are elevated by their ease of switching jobs. Conversely, the productivity-wage gap

[10] The JOLTS data series defines other separations as separations stemming from retirements as well as discharges due to reasons of disability.

[11] Since the SIPP only surveys workers, we cannot ascertain whether a hire was a replacement hire for the firm.

would be increasing in the replacement hiring share if firm OJS is the main driver of replacement hiring. Using data from the NBER-CES Manufacturing Industry Database, we show in Appendix A.5 that a positive relationship exists between the productivity-wage gap and the replacement hiring share both in the aggregate time-series and in the cross-section. Furthermore, as predicted by our model (as we discuss in Section 4), Table 5 in Appendix A.5 shows that the pass-through from productivity to wages is lower when the replacement hiring share is high. Overall, our findings of a positive relationship between the productivity-wage gap with replacement hiring share, as well as a lower growth rate of wages with productivity among industries with higher replacement hiring shares suggest that firm OJS may not only be a non-trivial factor in replacement hiring, but that it also plays a role in the divergence of the productivity-wage gap.

In summary, our results suggest that the standard labor search model may be missing an important feature: OJS by firms. We outline in our model section how firm OJS and worker OJS - both of which contribute to the incidence of replacement hiring - have contrasting implications for the emergence of a productivity-wage gap.

3 Model

Time is continuous and runs forever. The economy comprises of a unit mass of ex-ante identical infinitely-lived risk-neutral workers, who discount the future at rate ρ. Workers are either employed or unemployed: unemployed workers receive flow utility b. The other agents in the economy are firms each of which can employ at most one worker at any date. A firm-worker pair with match quality x produces x units of output at each date. The match quality $x \in [0, \overline{x})$ is drawn from a time invariant distribution $\Pi(x)$ at the time the firm and worker meet and remains constant for the duration of the match.[12]

Vacancies and Firms Search is random. A firm incurs a fixed cost χ to post a vacancy. Posting a vacancy in our model is synonymous with creating a job position. We will thus use the term vacancies interchangeably with job positions. A filled vacancy corresponds to a matched firm-worker pair. All firms enter the labor market initially as unfilled vacancies. Importantly, unfilled vacancies do not expire instantly, implying that a vacancy that goes unmatched today can still contact an applicant in the future as long as the vacancy has not been destroyed. Firms whose vacancies have been filled (referred to as *recruiting matched firms*) can continue to meet new applicants without posting a new vacancy, i.e. firms can search while on-the-job. If the recruiting matched firm chooses to replace its current worker with the new job applicant, it releases its current worker into unemployment. In the case where the worker leaves the firm and the firm is unable to find a replacement, recruiting matched firms become unfilled vacancies. If a firm with an unfilled vacancy hires a worker, it becomes a recruiting matched firm. Finally, a vacancy or position is destroyed at rate δ. When an unfilled vacancy is destroyed, it ceases to exist, while when a currently filled vacancy experiences the same shock, both the existing match and the vacancy cease to exist. This shock can be thought of as a firm no longer needing a worker for a particular position.

[12] The support of x is allowed to be unbounded above, i.e., $\overline{x}$ can be ∞. In fact, in our calibrated model, we assume that x is described by a log-normal distribution and hence, the support is unbounded above.

Labor Market Both unemployed and employed workers can contact vacancies. Unemployed workers meet vacancies (both currently unfilled and filled) at rate p while λ_w fraction of the currently employed workers can conduct on-the-job-search: the rate with which employed workers can meet vacancies is given by $\lambda_w p \leq p$. Similarly, an unfilled vacancy meets job-seekers (both currently unemployed and employed) at a rate q. Unlike in the standard model, λ_f fraction of recruiting matched firms, i.e. firms with currently filled vacancies, can also search on-the-job and meet applicants at an rate of $\lambda_f q \leq q$. The contact rates p and q are determined by a *meeting* technology $M = v^{1-\alpha}\ell^{\alpha}$, where $\ell = u + \lambda_w(1-u)$ denotes the mass of job-seekers and $v = v^u + \lambda_f v^m$ is the measure of vacancies that can be contacted. Vacancies include all the unfilled vacancies, v^u, and the fraction of the currently matched firms who receive an opportunity to search, $\lambda_f v^m$. ℓ includes all the unemployed workers, u, and the fraction of currently employed workers $1-u$ who get a chance to search on-the-job, $\lambda_w(1-u)$.[13]

Importantly, meeting rates are not equivalent to hiring rates. In order for a meeting to result in a hire, both firm and worker must agree to form a match. If an unfilled vacancy and an unemployed worker meet, they form a match whenever the match-specific productivity drawn is above a threshold $\widetilde{x}$, which is determined in equilibrium. However, if the unemployed individual meets a firm searching on-the-job, the new match quality x drawn must be at least as large as its incumbent worker's match quality. Thus, although the rate with which an unemployed worker meets a filled and unfilled vacancy is the same, the probability with which she will be hired is (weakly) lower at currently filled vacancies. Similarly, if an unfilled vacancy meets a currently employed worker, they form a new match only if they draw a new match productivity higher than that of the employed worker's old match. Finally, a meeting between a currently employed worker and a filled vacancy results in a new match only if the new match-productivity drawn exceeds that observed in both existing matches.

In summary, a firm-worker match can end if (i) the job is destroyed exogenously (ii) the worker successfully searches on the job and moves to a new match with a higher match-quality and (iii) the firm successfully searches on the job and hires a new worker with whom it shares higher match-productivity.

3.1 Firm's Problem

Recruiting matched firms The value of a filled vacancy (also referred to as a *recruiting matched firm*) with current match quality x can be written as:

$$\rho J(x) = x - w(x) + \delta\Big(J^0 - J(x)\Big) + p^*(x)\Big(J^u - J(x)\Big) + R(x) \tag{1}$$

The firm receives current profits $x - w(x)$ and can undergo three possible events in the future. First, the vacancy/job position is destroyed at a rate δ and ceases to exist. The firm can create a new unfilled vacancy and its associated change of value is $J^0 - J(x)$ where J^0 denotes the value of creating a new vacancy. Second, at a rate $p^*(x)$, the firm's current worker successfully searches on-the-job and quits the current firm to join another firm with a higher match quality. $p^*(x)$ can then be written as:

$$p^*(x) \;=\; \lambda_w p\left\{\left(\frac{v^u}{v}\right)[1-\Pi(x)] + \left(\frac{\lambda_f v^m}{v}\right)\left[[1-\Pi(x)]F(x) + \int_x^{\overline{x}}[1-\Pi(\varepsilon)]\,dF(\varepsilon)\right]\right\} \tag{2}$$

[13] Of course, consistency requires that $1-u = v^m$.

The events that lead a worker to endogenously separate from the firm can be described as follows: first, the currently employed worker meets a vacancy at rate $\lambda_w p$. Conditional on a meeting, the worker meets an unfilled vacancy with probability v^u/v and with probability $1 - \Pi(x)$ forms a new match, as it draws a match quality higher than their current x. With probability $1 - v^u/v = \lambda_f v^m/v$, the worker meets a filled vacancy with match quality ε; with probability $F(x)$ the filled vacancy's current match quality is lower than x and the new match is formed only if the pair draw a new match-quality larger than the worker's current match-quality x (which occurs with probability $1 - \Pi(x)$). Here, $F(\cdot)$ denotes the endogenous cumulative distribution function of existing matched firm-worker pairs across match quality with $F(\widetilde{x}) = 0$ and $F(\overline{x}) = 1$. The last term $\int_x^{\overline{x}} [1 - \Pi(\varepsilon)]\, dF(\varepsilon)$ represents the probability that a new match is formed when the employed worker with current match-quality x meets a filled vacancy with match quality $\varepsilon > x$ and they draw a new match-quality larger than ε. Finally, the last term, $R(x)$, in (1) denotes the expected value of OJS by a firm with current match quality x:

$$\begin{aligned} R(x) &= \lambda_f q \Big[\left(\frac{u}{\ell}\right) \int_x^{\overline{x}} [J(y) - J(x)]\, d\Pi(y) \\ &+ \left(\frac{\lambda_w v^m}{\ell}\right) \left\{ \int_x^{\overline{x}} [J(y) - J(x)]\, d\Pi(y)\, F(x) + \int_x^{\overline{x}} \int_\varepsilon^{\overline{x}} [J(y) - J(x)]\, d\Pi(y)\, dF(\varepsilon) \right\} \Big] \end{aligned} \tag{3}$$

A recruiting matched firm meets a new worker while searching on-the-job at the effective rate $\lambda_f q$. Conditional on the meeting, the first term is the change in value associated with the event that the firm meets an unemployed worker (with probability u/ℓ), draws a new match-quality $y > x$, forms the new match and enjoys a change of value $J(y) - J(x)$. The term on the second line reflects the expected change in value when the recruiting matched firm meets an employed applicant and a new match is formed. The first-term on the second line reflects the event when the firm with current match-quality x meets an employed applicant who has match quality $\varepsilon < x$ with her incumbent firm (this occurs with probability $F(x)$). In this case, the employed applicant with match-quality ε is always willing to form the new match if the firm with match quality $x > \varepsilon$ is willing to do so. Similarly, the second term on the second line refers to the event whenever the firm with match quality x meets an employed applicant with match-quality $\varepsilon \geq x$. In this case, it is the worker's decision to form a match which is binding.

Firms with unfilled vacancies The value of an unfilled vacancy can be written as:

$$\rho J^u = \delta \left[J^0 - J^u\right] + q \left\{ \left(\frac{u}{\ell}\right) \int_{\widetilde{x}}^{\overline{x}} [J(y) - J^u]\, d\Pi(y) + \left(\frac{\lambda_w v^m}{\ell}\right) \int_{\widetilde{x}}^{\overline{x}} \int_\varepsilon^{\overline{x}} [J(y) - J^u]\, d\Pi(y)\, dF(\varepsilon) \right\} \tag{4}$$

An unfilled vacancy earns zero flow profits. The vacancy is destroyed at rate δ (associated with the change of value $J^0 - J^u$). At rate q, the firm meets an applicant; with probability $\frac{u}{\ell}$, the applicant is unemployed. The unemployed worker and unfilled vacancy form a match as long as the match-quality they draw, y, is above the reservation match quality, $\widetilde{x}$. The firm's gain from such a match is $J(y) - J^u$, and the reservation value $\widetilde{x}$ is defined as the lowest x for which the firm's gain is non-negative:

$$J(\widetilde{x}) - J^u = 0 \tag{5}$$

In the complementary case, i.e. with probability $1 - u/\ell = \lambda_w v^m/\ell$, the unfilled vacancy meets an employed worker with current match-quality ε. They form a new match only if they draw a new match-quality $y > \varepsilon$ in which case the firm's change in value is $J(y) - J^u$. Here, the composition of job-seekers affects the rate with which an unfilled vacancy becomes filled - holding all else fixed, a greater fraction of employed job-seekers searching on-the-job lowers the hiring rate of an unfilled vacancy since the employed worker only moves to a new match if the match quality drawn is higher than the existing value she shares with her incumbent firm.

Free Entry Under free-entry, the value of creating a new vacancy is driven down to 0:

$$J^0 = -\chi + J^u = 0 \qquad \Rightarrow \qquad J^u = \chi > 0, \tag{6}$$

implying that an unexpired vacancy provides the firm with a positive option value since it allows the firm to continue searching tomorrow even if it rejects or fails to meet a worker today. Furthermore, as we discuss subsequently, this positive option value raises the recruiting matched firm's outside option, allowing it to bargain wages down when bargaining with the worker.

3.2 Worker's Problem

Unemployed workers The value of an unemployed worker, U, can be written as:

$$\rho U = b + p\left\{\left(\frac{v^u}{v}\right)\int_{\widetilde{x}}^{\overline{x}}\left[W\left(y\right) - U\right]d\Pi\left(y\right) + \left(\frac{\lambda_f v^m}{v}\right)\int_{\widetilde{x}}^{\overline{x}}\int_{\varepsilon}^{\overline{x}}\left[W\left(y\right) - U\right]d\Pi\left(y\right)dF\left(\varepsilon\right)\right\}, \tag{7}$$

where $F(\varepsilon)$ denotes the fraction of recruiting matched firms whose worker possesses match quality ε or lower and $W(y)$ is the value of a worker who is employed at a recruiting firm with match quality y. The value of unemployment can be decomposed into two terms: b, the flow utility associated with home production and the second term in equation (7) which denotes the expected change in value that the worker enjoys in the event that they transition to employment in the future. At a rate p, an unemployed worker meets a vacancy. With probability v^u/v, this vacancy is currently unfilled and the worker is accepted whenever they draw a match quality $x > \widetilde{x}$. However, with probability $\lambda_f v^m/v$, the unemployed worker encounters a recruiting matched firm and is only hired when they draw a match quality y that is higher than the incumbent's value. The second term inside the parenthesis captures the unemployed worker's change in value when she is accepted by a recruiting matched firm with current match quality ε weighted by the probability of meeting such a firm.

The introduction of firm OJS affects the composition of vacancies which in turn affects the worker's value of unemployment. Holding all else constant, a higher $\lambda_f v^m/v$ implies that unemployed workers are more likely to encounter recruiting matched firms as opposed to unfilled vacancies. This tends to lower the rate at which workers exit unemployment because recruiting matched firms require unemployed applicants to draw a match productivity above their incumbent worker's match quality. Thus, holding all else constant, a higher $\lambda_f v^m/v$ makes the the wedge between meeting and hiring rates larger, i.e. it lowers *measured matching efficiency*, lowering the worker's value of unemployment.

Employed workers The value of an employed worker at a recruiting firm with match quality x is:

$$\rho W(x) = w(x) - \Big(\delta + q^*(x)\Big)[W(x) - U] + H(x) \tag{8}$$

where $w(x)$ denotes the wages paid. There are two events that transition the worker into unemployment, resulting in a change in value of $U - W(x)$. First, at rate δ, the vacancy is destroyed, and the worker transitions to unemployment. Second, the worker experiences a layoff whenever its firm meets a new applicant and forms a new match at rate $q^*(x)$, which is defined as

$$q^*(x) = \lambda_f q \left\{ \left(\frac{u}{\ell}\right)[1 - \Pi(x)] + \left(\frac{\lambda_w v^m}{\ell}\right)\left[[1 - \Pi(x)] F(x) + \int_x^{\overline{x}} [1 - \Pi(\varepsilon)]\, dF(\varepsilon)\right]\right\} \tag{9}$$

The events which add up to the worker being endogenously displaced into unemployment are as follows: the firm they are currently matched with meets an new applicant at rate $\lambda_f q$. Conditional on a meeting, the firm meets an unemployed applicant with probability u/ℓ and forms a match as long as the new match quality is higher than the current x. With probability $1 - u/\ell = \lambda_w v^m/\ell$ the firm meets a currently employed worker with match quality ε; with probability $F(x)$ the worker's current match quality, ε, is lower than x and a new match is formed if the pair draws a match quality, $y \geq x$. The last term $\int_x^{\overline{x}} [1 - \Pi(\epsilon)]\, dF(\epsilon)$ represents the probability that a new match is formed when the firm with match-quality x meets a currently employed worker with match quality $\varepsilon > x$, in which case the match is only formed if the new match-quality is larger than ε.

The value of an employed worker with match-quality x also includes the value of worker OJS as denoted by $H(x)$:

$$\begin{aligned} H(x) &= \lambda_w p \Bigg\{ \left(\frac{v^u}{v}\right) \int_x^{\overline{x}} [W(y) - W(x)]\, d\Pi(y) \\ &\quad + \left(\frac{\lambda_f v^m}{v}\right)\left[\int_x^{\overline{x}} [W(y) - W(x)]\, d\Pi(y)\, F(x) + \int_x^{\overline{x}} \int_\varepsilon^{\overline{x}} [W(y) - W(x)]\, d\Pi(y)\, dF(\varepsilon)\right] \Bigg\} \end{aligned} \tag{10}$$

A worker searching on-the-job meets a vacancy at rate $\lambda_w p$. Conditional on meeting, the first term is the change in value experienced by the worker with current match-quality x when they meet an unfilled vacancy, draw a new match-quality $y > x$ and form a new match, resulting in a change of value of $W(y) - W(x)$. The term on the second line reflects the expected change in value when the currently employed worker with quality x meets a recruiting matched firm. The first-term on the second line reflects the event when the worker meets a currently filled vacancy who has a match quality $\varepsilon < x$. They form a match as long as the new match-quality is greater than x. Similarly, the second term on the second line denotes the event when the employed worker meets a filled vacancy with match-quality $\varepsilon \geq x$, in which case, a new match is only formed if the pair draws a match-quality $y \geq \varepsilon$.

The introduction of firm OJS introduces additional *job insecurity* for the worker through endogenous separations. Holding all else constant, if the ease of firm OJS increases (higher λ_f), then $q^*(x)$ rises and workers' employment spells are shortened. This has the effect of lowering workers' employment values, which in turn lower the value of unemployment, ρU.

3.3 Surplus and Wage Formation

Wage Determination Wages are determined at each date via Nash Bargaining:

$$w(x) = \arg\max_{w(x)} \Big[J(x) - J^u\Big]^{1-\eta} \Big[W(x) - U\Big]^{\eta} \tag{11}$$

where $\eta \in [0, 1]$ denotes the bargaining power of a worker. Bargaining over wages takes place only after matches have been formed. This implies that whenever a recruiting matched firm chooses to hire a new applicant, he releases his current worker into unemployment prior to bargaining with the new applicant. Similarly, whenever a currently employed worker chooses to form a match with a different vacancy, she first vacates her current job. We further assume that there are no recalls. As such, when the firm with match quality x and a new applicant bargain over wages, the firm's outside option is simply the positive option value of an unfilled vacancy, J^u, and not $J(x)$. Similarly, for an employed individual with current match quality y, the worker's outside option is U and not $W(y)$.[14] As is well known, the Nash bargaining solution implies that the surplus is split between firm and worker such that:

$$J(x) - J^u = (1-\eta)S(x) \qquad \text{and} \qquad W(x) - U = \eta S(x) \tag{12}$$

The surplus $S(x)$ of a match is the (discounted) total output produced by the firm-worker pair less their individual relative gains from continuing to search unmatched. Manipulating equations (1),(4),(7) and (8), the surplus for a matched firm-worker pair with match quality x can be written as:

$$\Big(\rho + \delta + q^*(x) + p^*(x)\Big)S(x) \quad = \quad x - \Big[\rho U - \widehat{H}(x)\Big] - \Big[(\rho+\delta)\,\chi - \widehat{R}(x)\Big] \tag{13}$$

where $\widehat{H}(x) = H(x) + p^*(x)\eta S(x)$ is the expected value the worker gets from conducting OJS less the value of unemployment and $\widehat{R}(x) = R(x) + q^*(x)(1-\eta)S(x)$ is the expected value the firm gets from conducting OJS less the value of an unfilled vacancy.[15] (13) shows that the surplus of the match is given by output x less the worker's *effective* outside option, $\rho U - \widehat{H}(x)$, and less the firm's *effective* outside option, $(\rho+\delta)\chi - \widehat{R}(x)$. Because both workers and firms can search on-the-job, their *relative* gain from walking away from a match of quality x and continuing to search as an unmatched agent is not just the value of unemployment or the value of an unfilled vacancy. Because the worker can search on-the-job, they can continue to meet vacancies at rate $\lambda_w p$ and will re-match with firms with quality $y > x$. Hence, the relative gain to a worker from walking away from a match of quality x is the opportunity to meet vacancies at a higher rate of p as well as the potential to form matches between $\widetilde{x}$ to x. Similarly, because the firm can also search on-the-job, its relative gain from walking away from a match of quality x is the opportunity to meet applicants at the higher rate of q as well as the potential to make matches between $\widetilde{x}$ to x. As such, the relative gain of continuing to search as an unmatched

[14]This assumption is without loss of generality since wages are determined via Nash Bargaining each period without commitment. Even if firms bargained before separating with their current worker, and effectively used $J(y)$ as their outside option, it would mean that at the instant the next match is formed, it would revert to having J^u as its current outside option and would have to pay workers wages commensurate with equation (11). Of course, if the environment featured commitment by agents in the form of long-term contracts, then this would not be true and in that scenario, currently matched recruiting firms would offer a lower wage than unfilled vacancies for an applicant with the same match quality.

[15]See Appendix B for more detail.

agent for the firm and the worker is characterized by their *effective* outside options. In Section 4, we outline how changes in effective outside options affect the pass-through of productivity to wages.

3.4 Labor Market Flows

Having described the relevant value functions, we proceed to describe labor market flows next.

Unemployed The steady state rate of unemployment u satisfies:

$$q\left(\frac{u}{\ell}\right)\left[1-\Pi\left(\widetilde{x}\right)\right]v^u = \delta v^m + 2q\left(\frac{\lambda_f v^m \times \lambda_w v^m}{\ell}\right)\int_{\widetilde{x}}^{\overline{x}}\left[1-\Pi\left(z\right)\right]F\left(z\right)dF\left(z\right) \tag{14}$$

The LHS represents outflows from the pool of unemployed. At rate qu/ℓ, an unfilled vacancy meets an unemployed worker and hires them if they draw a match quality above $\widetilde{x}$. Notice that there is no net outflow when a currently filled vacancy hires an unemployed worker, as it also releases its current worker into unemployment. This feature of firm OJS distinguishes it from worker OJS. Note that when a worker conduct OJS succesfully, they leave their current firm, causing an unfilled vacancy to open up and creating the start of a vacancy chain.[16] Instead, if a firm conducts OJS and hires a worker out of unemployment, it does not create a vacancy chain nor does it affect the unemployment pool on net, since hiring a worker out of unemployment requires it to displace its incumbent worker into unemployment.

The RHS of (14) denotes flows into unemployment. The first term, δv^m, is the fraction of all currently employed workers who are exogenously separated because their position is destoryed (at rate δ). The second term denotes flows into unemployment when a employed worker forms a match with a currently filled vacancy, displacing the filled vacancy's incumbent worker into unemployment.

Unfilled vacancies Since vacancies are long-lived, the stock of unfilled vacancies, v^u in steady state is implicitly defined by:

$$q\left(\frac{u}{\ell}\right)\left[1-\Pi\left(\widetilde{x}\right)\right]v^u + \delta v^u = v^{new} + 2q\left(\frac{\lambda_f v^m \times \lambda_w v^m}{\ell}\right)\int_{\widetilde{x}}^{\overline{x}}\left[1-\Pi\left(z\right)\right]F\left(z\right)dF\left(z\right) \tag{15}$$

The LHS of (15) denotes outflows from the pool of unfilled vacancies. The first term, $q\left(\frac{u}{\ell}\right)\left[1-\Pi\left(\widetilde{x}\right)\right]v^u$, is the number of unfilled vacancies which met an unemployed worker and formed a match. When an unfilled vacancy poaches a currently employed worker, there is no net-outflow from the pool of unfilled vacancies since the worker leaves the pre-existing match, transitioning that vacancy into an unfilled vacancy. The second term, δv^u, represents the unfilled vacancies which are destroyed.

The RHS of (15) represents inflows into the pool of unfilled vacancies. The first component of inflows is the flow of newly created vacancies, v^{new}. Importantly, v^{new} is not counted as part of the vacancies available for matching today.[17] In the continuous time limit, $\theta = (v^u + \lambda_f v^m)/\ell \equiv v/\ell$. Thus, workers can only match with existing/old vacancies. New vacancies only add to the stock of unfilled vacancies

[16] Both Elsby et al. (2019) and Mercan and Schoefer (2020) explore how worker OJS can give rise to vacancy chains, which are defined as the phenomenon where vacancies beget more vacancies.

[17] The total vacancies available for matching at time t are given by $v_t = (1-\delta\Delta)(v^u_{t-\Delta} + \lambda_f v^m_{t-\Delta}) + v^{new}_t\Delta$ where Δ is the length of one period, $(1-\delta\Delta)(v^u_{t-\Delta} + \lambda_f v^m_{t-\Delta})$ is the stock of unexpired vacancies from the end of period $t-\Delta$. v^{new}_t is the number of new vacancies posted per unit time. Since each period is Δ units long, the total number of new vacancies

in the future. The second term represents the inflows that occur when a matched vacancy and employed worker form a new match, causing the old vacancy which employed the worker to become unfilled.

Endogenous distribution of match-productivity The steady state distribution of matched firm-worker pairs across match qualities $F(x)$ is implicitly given by:

$$\begin{aligned} q\left(\frac{u}{\ell}\right)\left[\Pi\left(x\right)-\Pi\left(\widetilde{x}\right)\right]v^{u} \;=\;& \delta F\left(x\right)v^{m}+q\left(\frac{u}{\ell}\right)F\left(x\right)\lambda_{f}v^{m}\left[1-\Pi\left(x\right)\right]+p\left(\frac{v^{u}}{v}\right)F\left(x\right)\lambda_{w}v^{m}\left[1-\Pi\left(x\right)\right] \\ &+2q\left(\frac{\lambda_{f}v^{m}\lambda_{w}v^{m}}{\ell}\right)\left\{\left[1-\Pi\left(x\right)\right]F\left(x\right)+\int_{x}^{\overline{x}}\left[1-\Pi\left(\varepsilon\right)\right]dF\left(\varepsilon\right)\right\}F\left(x\right) \\ &+q\left(\frac{\lambda_{f}v^{m}\lambda_{w}v^{m}}{\ell}\right)\left\{\int_{\widetilde{x}}^{x}\int_{z}^{x}\left[\Pi\left(x\right)-\Pi\left(\varepsilon\right)\right]dF\left(\varepsilon\right)dF\left(z\right)\right. \\ &\left.+\int_{\widetilde{x}}^{x}\left[\Pi\left(x\right)-\Pi\left(z\right)\right]F\left(z\right)dF\left(z\right)\right\} \qquad \text{for } x\in\left(\widetilde{x},\overline{x}\right) \end{aligned} \tag{16}$$

with $F(\widetilde{x}) = 0$ and $F(\overline{x}) = 1$. The LHS of (16) represents the inflow into the set of matched-vacancies with match quality between $\widetilde{x}$ and x and is the measure of unfilled vacancies which match with an unfilled worker and draw a match quality $y \in [\widetilde{x}, x]$. The RHS of (16) denotes outflows from the same set. The first term on the RHS ($\delta F(x)v^m$) denotes the measure of matched-vacancies with match-quality less than x that are destroyed. The second term represents the measure of currently matched-vacancies who successfully matched with an unemployed worker and drew a new match-quality above x, thus reducing the number of matches with match-quality below x. The third term is the measure of currently employed workers with match-quality less than x who successfully match with an unfilled vacancy and draw a new match-quality greater than x. The second line of (16) describes the case where an employed worker with $\epsilon < x$ and a filled vacancy with $z < x$ meet, and they draw $y > x$, then two firm-worker pairs leave the measure of matched pairs with match quality less than or equals to x. The third (and fourth) line of (16) describes the case where an employed worker with $\epsilon < x$ and a filled vacancy with $z < x$ meet, and they draw $\max\{z, \epsilon\} < y \le x$, then one firm-worker pair leaves the distribution of firm-worker pairs with match quality less than x.

The distribution of matches by match-quality $F(x)$ is informative about the replacement hiring share. Holding all else constant, a distribution $F(x)$ which is skewed towards low values of x, indicates that there is substantial room for matched-firms to find a better match and thus to conduct replacement hiring. Similarly, employed workers also have substantial room to find a better match by searching on-the-job. When these workers find better matches and leave the firm, the firm with an unfilled vacancy must find a replacement, again encouraging replacement hiring. In contrast, a $F(x)$ with matches concentrated around higher values of x, both matched firms and employed workers find it harder to find better matches, reducing replacement hiring.

posted in period t is $v_t^{new}\Delta$. Thus, market tightness can be written as:

$$\theta_t = \frac{(1-\delta\Delta)(v_{t-\Delta}^u + \lambda_f v_{t-\Delta}^m) + v_t^{new}\Delta}{u_{t-\Delta} + \lambda_w v_{t-\Delta}^m}$$

In the continuous time limit, $\Delta \to 0$, the term $v^{new}\Delta$ becomes vanishingly small implying that current vacancies available for matching at period t consist only of existing or *old* vacancies $v_t^u + \lambda_f v_t^m$.

3.5 Closing the Model

The model, so far, has been summarized by the surplus equations and labor market flows. However, these relationships depend on the reservation match quality, $\widetilde{x}$, and the job-filling rate q (which is a function of labor market tightness θ). Lemma 1 summarizes the equations which pin down the equilibrium $(\tilde{x}, \theta)$:

Lemma 1. *In steady state, the equilibrium $\tilde{x}$ and θ are determined by the following equations:*

$$
\begin{aligned}
(\rho+\delta)\,\chi &= (1-\eta)\,q\left[\left(\frac{u}{\ell}\right)\int_{\widetilde{x}}^{\overline{x}} S(y)\,d\Pi(y) + \left(\frac{\lambda_w v^m}{\ell}\right)\int_{\widetilde{x}}^{\overline{x}}\int_{\varepsilon}^{\overline{x}} S(y)\,d\Pi(y)\,dF(\varepsilon)\right] && (17)\\
\widetilde{x} &= \rho U - \eta\lambda_w p\left[\left(\frac{v^u}{v}\right)\int_{\widetilde{x}}^{\overline{x}} S(y)\,\pi(y)\,dy + \left(\frac{\lambda_f v^m}{v}\right)\int_{\widetilde{x}}^{\overline{x}} S(y)\,F(y)\,\pi(y)\,dy\right]\\
&\quad + (1-\lambda_f)\,q\,(1-\eta)\left[\left(\frac{u}{\ell}\right)\int_{\widetilde{x}}^{\overline{x}} S(y)\,\pi(y)\,dy + \left(\frac{\lambda_w v^m}{\ell}\right)\int_{\widetilde{x}}^{\overline{x}} S(y)\,F(y)\,\pi(y)\,dy\right] && (18)
\end{aligned}
$$

where $S(x)$ and $F(x)$ are defined in (13) and (16). The value of unemployment ρU is given by:

$$
\rho U = b + \eta p\left\{\left(\frac{v^u}{v}\right)\int_{\widetilde{x}}^{\overline{x}} S(y)\,d\Pi(y) + \frac{\lambda_f v^m}{v}\int_{\widetilde{x}}^{\overline{x}}\int_{\varepsilon}^{\overline{x}} S(y)\,d\Pi(y)\,dF(\varepsilon)\right\}
$$

Proof. See Appendix B. ☐

(17) is the free-entry condition where we have used $J^u = \chi$ from (6) and the solution to the Nash bargaining problem (12): $J(x) - \chi = (1-\eta)S(x)$ in (4). (17) describes the lowest match-quality for which an unfilled vacancy is willing to form a match for a given θ - or how *selective* a firm is as a function of labor market tightness, and implies a negative relationship between $\widetilde{x}$ and θ. In a slack labor market (low θ, high q), holding out for a better worker is relatively costless for the firm, and hence the firm raises its minimum level of match quality $\widetilde{x}$ for which it is willing to accept a worker. Conversely, in a tight labor market (low q), holding out for a better applicant is costly as the firm is unlikely to meet another applicant soon. As such, tight labor markets are associated with lower firm selectivity.

(18) can be interpreted as the *worker's indifference locus*: given market tightness θ, it defines the reservation match quality for which a worker will be willing to exit unemployment and form a match. The higher the value of unemployment, ρU, the more *selective* a worker is, i.e. a higher $\widetilde{x}$. Since a tighter labor market (higher θ) implies a higher value of unemployment ρU, (18) implies a positive relationship between $\widetilde{x}$ and θ. Figure 4 depicts the worker's indifference curve and shows the upward sloping relationship between θ and $\widetilde{x}$. Notably, both λ_w and λ_f affect the worker's indifference locus. Higher λ_w makes a worker less selective, because they can easily search on-the-job for a better match even if they accept a low quality match out of unemployment. A higher λ_f, or greater ease with which a firm can search on-the-job also lowers the worker's reservation $\widetilde{x}$. A higher λ_f allows a firm to replace a worker easily, reducing the worker's value of remaining unmatched by pushing down the wage that a worker receives for any given match-quality x as we show next. Figure 4 depicts the free entry and the workers indifference locus in $(\theta, \widetilde{x})$ space : the equilibrium level of selectivity $\widetilde{x}$ and labor market tightness θ is given by the intersection of the two curves.

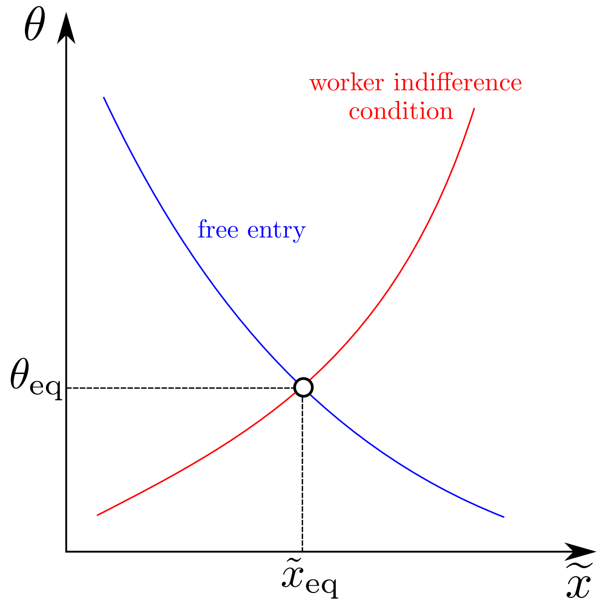


Figure 4: Equilibrium $\widetilde{x}$ and θ

4 Forces at Play

Changes in the ease with which firms and workers can search on-the-job (λ_f and λ_w respectively) has implications for the behavior of average wages and labor productivity. To identify exactly how changes in λ_w and λ_f affect average wages and labor productivity differently, it is useful to work with the two polar cases: where either only worker OJS is operative ($\lambda_f = 0$) or firm OJS is operative ($\lambda_w = 0$). It is useful to consider these special cases, because the model simplifies and admits many closed form expressions, allowing us to better understand the results from our quantitative exercise in Section 5 which uses the general model in which both $\lambda_w, \lambda_f \neq 0$. In what follows, we conduct comparative static exercises where we hold $\widetilde{x}$ and θ constant. We do this because changing either λ_w or λ_f causes both the free entry curve and the worker's indifference locus to shift and knowing what happens to equilibrium θ and $\widetilde{x}$ depends on the relative magnitude to which each curve moves. As such, the following comparative static results represent a *partial* equilibrium analysis. Of course, when we proceed to the quantitative analysis, we will also consider the general equilibrium feedback.

4.1 Only Worker OJS

4.1.1 Productivity

We start by shutting off firm OJS, i.e. $\lambda_f = 0$, and consider how variations in λ_w, the ease with which workers can search on-the-job, affect the productivity distribution as well as wages. IWith $\lambda_f = 0$, the distribution of match-quality among employed firm-worker pairs, (16), simplifies to:

$$F(x) = \frac{\delta}{\delta + \lambda_w p \left[1 - \Pi(x)\right]} \frac{\Pi(x) - \Pi(\widetilde{x})}{1 - \Pi(\widetilde{x})} \tag{19}$$

(19) reveals that for a given $(\widetilde{x}, \theta)$, $F(x \mid \lambda_w^{high})$ first-order stochastically dominates $F(x \mid \lambda_w^{low})$ for $\lambda^{high} < \lambda^{low}$. This implies that the average productivity is higher with a higher λ_w:

$$\int_{\widetilde{x}}^{\overline{x}} x dF(x \mid \lambda_w^{high}) dx \geq \int_{\widetilde{x}}^{\overline{x}} x dF(x \mid \lambda_w^{low}) dx$$

Intuitively, when workers have greater opportunity (higher λ_w) to conduct OJS, they find it easier to move to higher match-quality jobs which also pay higher wages. Consequently, more matches tend to be concentrated around higher x's, which also raises average productivity.

4.1.2 Pass-through

What matters for the productivity-wage gap is the extent to which productivity passes through to wages. If a higher λ_w raised average productivity but kept the pass-through from productivity to wages constant, then there would be no change in the productivity-wage gap as average wages would rise together with average productivity. For a wider productivity-wage gap to emerge, the pass-through from productivity to wages must be lower. We measure pass-through as how much of a marginally higher x translates into higher wages, i.e., $w'(x)$. To understand how $w'(x)$ varies with λ_w, it is useful to examine what surplus, effective outside options, and pass-through look like in equilibrium in the limit case where $\lambda_f = 0$. The following Lemma describes the equilibrium outcomes for this case.

Lemma 2. *In the limit where $\lambda_f = 0$, the surplus of a match with quality x takes the form of:*

$$\Big(\rho + \delta + \lambda_w p\big[1 - \Pi(x)\big]\Big) S(x) = x - (\rho + \delta) J^u - \Big(\rho U - \widehat{H}(x)\Big) \tag{20}$$

Correspondingly, the worker's effective outside option in a match of quality x is given by

$$\rho U - \widehat{H}(x) = \widetilde{x} - (\rho + \delta) J^u + \lambda_w p \eta \int_{\widetilde{x}}^{x} S(y) d\Pi(y) \tag{21}$$

Finally, the extent to which improvements in x are passed through to wages are given by:

$$w'(x) = \eta + (1 - \eta) \lambda_w p \eta S(x) \pi(x) \tag{22}$$

Proof. See Appendix C.1. □

When only worker OJS is operative, (20) makes clear that the (discounted) surplus of a firm-worker pair with match-quality x is given by the output x less the firm's outside option, $(\rho+\delta)J^u$, and less the worker's *effective* outside option, $\rho U - \widehat{H}(x)$. Because workers can search on-the-job, they can continue to meet firms at rate $\lambda_w p$ and will re-match with unfilled vacancies with whom they share match quality $y \in [x, \overline{x}]$. This implies that the worker's relative gain from disagreeing to a match of quality x and continuing to search in unemployment - in other words, her *effective* outside option - is affected by the foregone opportunity of matching with firms with quality from $\widetilde{x}$ to x. (21) shows that the worker's effective outside option is equal to the reservation match quality, $\widetilde{x}$ less what must be given to the firm to ensure its participation, $(\rho + \delta)J^u$, and plus the amount the worker must be compensated for her foregone opportunity of matching with vacancies with quality ranging from $\widetilde{x}$ to x. Finally, (22) denotes the pass-through from productivity to wages.

(22) shows that for given $\widetilde{x}$ and θ, a higher λ_w raises the pass-through from productivity to wages $w'(x)$.[18] To understand why pass-through is higher, it is useful to examine how the worker's effective outside option is changing with λ_w. First, observe that in agreeing to form a match of quality x, the compensation the worker must receive for her foregone opportunity of matching with firms with quality $\widetilde{x}$ to x, i.e. the last term on the RHS of (21), is rising in λ_w. In other words, a higher λ_w by increasing the employed worker's contact rate with vacancies, elevates the worker's bargaining position and raises the amount of compensation the firm must give to the worker to ensure her participation. At the same time, an increase in λ_w also weakens how much the worker must give the firm to ensure its participation. Eq. (4) shows that the firm's outside option, $(\rho + \delta)J^u$, is affected by the composition of job-seekers. When the composition of job-seekers tilts towards that of employed job-seekers- which is the case when λ_w is higher holding all else constant - the probability that an unfilled vacancy forms a match is lower. For an unfilled vacancy to successfully hire an employed worker, it must draw a match quality higher than that which the worker currently shares with her incumbent firm. A higher λ_w, holding all else constant, shifts the composition of job-seekers towards employed workers, reducing the average acceptance rate for an unfilled vacancy and thus lowering its value. The combined effect of increased compensation for the worker for her foregone opportunities as well as a diminished firm outside option implies that the worker's effective outside option is rising in λ_w, allowing the worker to extract a larger share of productivity to be passed into wages. Overall, holding all else constant, a higher λ_w raises average productivity but also increases the pass-through of productivity to wages. This latter effect acts towards narrowing the productivity-wage gap.

4.2 Firm On-the-Job Search Only

4.2.1 Productivity

We now consider the case where only firms can search on-the-job, $\lambda_f > 0, \lambda_w = 0$. Again, this limit case permits us a closed form expression for the distribution of matched firm-worker pairs $F(x)$:

$$F(x) = \frac{\delta}{\delta + \lambda_f q \left[1 - \Pi(x)\right]} \frac{\Pi(x) - \Pi(\widetilde{x})}{1 - \Pi(\widetilde{x})} \tag{23}$$

(23) shows that when firms have a higher ease of searching on-the-job (higher λ_f), they can re-match more often and move into higher quality matches. Given $\widetilde{x}$ and θ, $F(x \mid \lambda_f^{high})$ first-order stochastically dominates $F(x \mid \lambda_f^{low})$ for $\lambda_f^{high} > \lambda_f^{low}$, i.e., average productivity is higher when firms have a higher ease of conducting OJS as they find it easier to meet new applicants and form higher quality matches.

4.2.2 Pass-through

With $\lambda_w = 0$, equilibrium outcomes are described by the following Lemma.

[18] While $S(x)$ is also affected by λ_w, Appendix C.1 makes clear that $w'(x)$ is increasing in λ_w.

Lemma 3. *In the limit where $\lambda_w = 0$, the surplus of a match of quality x is given by:*

$$\Big(\rho + \delta + \lambda_f q[1 - \Pi(x)]\Big) S(x) = x - \rho U - \Big((\rho + \delta)J^u - \widehat{R}(x)\Big) \tag{24}$$

the firm's effective outside option is given by:

$$(\rho + \delta)J^u - \widehat{R}(x) = \widetilde{x} - \rho U + \lambda_f q(1 - \eta) \int_{\widetilde{x}}^{x} S(y) d\Pi(y) \tag{25}$$

and pass-through of productivity to wages is given by:

$$w'(x) = \eta - \eta(1 - \eta)\lambda_f q S(x)\pi(x) \tag{26}$$

Proof. See Appendix C.2. □

(24) shows that the surplus of a firm-worker pair with match-quality x is given by output of that match less the worker's outside option, ρU, and the firm's *effective* outside option $(\rho + \delta)J^u - \widehat{R}(x)$. When firms can conduct OJS, they can continue to meet applicants at rate $\lambda_f q$ and will form new matches for any $y \in [x, \overline{x}]$. The firm's relative gain or effective outside option if it chooses to walk away from a match of quality x and search as an unfilled vacancy is $(\rho + \delta)J^u - \widehat{R}(x)$. (25) shows that the firm's effective outside option is given by the reservation match quality less what must given to the worker to ensure her participation and plus the amount that the firm must be compensated for foregoing the potential to match with workers of quality $\widetilde{x}$ to x. Finally, (26) captures the extent of pass-through from productivity to wages. As surplus is rising in x and wages are a function of surplus, wages are also increasing in x, implying that $w'(x) \geq 0$ for all x.[19]

As before, what matters for the productivity-wage gap is the pass-through from productivity to wages, $w'(x)$. Given $\widetilde{x}$ and θ, (26) shows that the pass-through $w'(x)$ is declining in λ_f. Intuitively, this arises because the firm's effective outside option is also increasing in λ_f. Consider firms who agree to a match of quality x. When firms have a greater ease of searching on-the-job, they require higher compensation for their foregone opportunity of matching with workers from $\widetilde{x}$ to x. The last term of equation 25 shows that the compensation a firm must receive for its foregone opportunity is rising in λ_f. At the same time, the outside option of workers, ρU, is declining when λ_f rises. (7), which depicts the value of unemployment, shows that the composition of vacancies affects this value. Given $\widetilde{x}$ and q, higher λ_f increases the fraction of vacancies which consist of firms searching on-the-job. Since unemployed workers are only hired by such vacancies when they draw a match quality higher than that of the firm's incumbent worker, the rate at which workers flow out of unemployment is lower. This lowers measured-matching-efficiency and reduces the value of unemployment. A lower ρU, together with the fact that firms must be compensated more for their foregone opportunity implies that the firm's effective outside option is increasing in λ_f, allowing them to extract more from surplus. This results in in a smaller pass-through from productivity to wages. Thus, unlike worker OJS, higher λ_f widens the productivity-wage gap as it shifts the distribution of matched firm-worker pairs to more productive

[19] One can differentiate (24) and show that the derivative of surplus with respect to x is positive: $\frac{dS(x)}{dx} = \frac{1+(1-\eta)\lambda_w p\pi(x)S(x)}{\rho+s+\delta+\lambda_w p[1-\Pi(x)]} > 0$. Since wages increase with surplus, this implies that $w'(x) = \frac{dw(x)}{dS(x)}\frac{dS(x)}{dx} > 0$

matches, raising average productivity, but lowers the pass-through from productivity to wages.

4.3 Pass-through from productivity to wages

More generally, with both $\lambda_w, \lambda_f \neq 0$, (27) expresses the relationship between pass-through $w'(x)$, the relative ease of worker OJS λ_w and the relative ease of firm OJS λ_f:

$$w'(x) = \eta + (1-\eta)\,\eta \left[\lambda_w p \frac{v^u}{v} - \lambda_f q \frac{u}{\ell}\right] S(x)\,\pi(x) \tag{27}$$

Holding ($\widetilde{x}$,θ) fixed, (27) shows that a higher λ_w increases pass-through while a higher λ_f decreases pass-through. Because in equilibrium, both $\widetilde{x}$ and θ also vary with changes in λ_f and λ_w, we now solve the model numerically to determine how much firm and worker OJS affect the productivity-wage gap.

5 Quantiative Analysis

Our goal is to examine if our model, calibrated to match labor market flow rates, can capture the increase in the productivity-wage gap. Since the divergence in the productivity-wage gap became more severe post 2000, we split the time periods into a pre-2000 (1990-1999) and a post-2000 (2000-2017) period. We separately calibrate the parameters of our model to each time period's labor market flows.

5.1 Calibration

We use a monthly calibration, implying a discount rate $\rho = 0.004$ to reflect an annual interest rate of about 5%. We set the bargaining weight, $\eta = 0.72$ following Shimer (2005), and the elasticity of the matching function with respect to job-seekers, $\alpha = 0.5$, which is within the range of values reported by Petrongolo and Pissarides (2001). The distribution of match quality $\Pi(x)$ is log-normal: $\ln x \sim N(0, \sigma_x^2)$. This leaves us with six parameters to calibrate $\lambda_f, \lambda_w, b, \chi, \sigma_x, \delta$ for the first time period. When calibrating the model to the second time period, we assume that the the distribution of match quality, $\Pi(x)$, and the value of home production, b are unchanged. In the second time period, we only re-calibrate $\lambda_f, \lambda_w, \chi, \delta$. These parameters affect the ability of the firm and worker to conduct OJS (λ_f, λ_w), as well as the firm's outside option, χ. The rate at which positions are destroyed, δ, also affects the firm's ability to conduct on-the-job search and the incidence of replacement hiring; longer-lived firms have more opportunities to conduct on-the-job search and to re-fill vacated positions.

While all parameters are jointly calibrated, we use the following moments to identify the parameters: to pin down λ_f, we target the average layoff-to-quits ratio as reported in the SIPP for each of the two time periods. To pin down λ_w, we target the employment-to-employment transition (EE) probability. We target the employment-to-unemployment transition (EU) probability to pin down δ. Finally, we target an unemployment rate of 5% across both time periods to pin down χ. We keep the unemployment rate constant across both time periods to ensure that any rise in the productivity-wage gap, is not due to rising unemployment. We target σ_x with the monthly job-finding rate as the dispersion on offers affects the job-finding rate through the minimum quality job a worker is willing to accept. Following Hall (2009), we target a replacement ratio of 0.7 to pin down b, the value of home production.

Unlike in the standard model, targeting any two out of the three following moments: exit rate from employment, the job-finding rate and the unemployment rate, does not automatically imply the third. This is because there is a distinction between gross and net flows in our model. The exit rate from employment is a function of *gross* separations which is composed of both exogenous job destruction and endogenous separations stemming from firm OJS. The job-finding rate out of unemployment is affected by the rate at which an unemployed worker meets and is hired by both unfilled and filled vacancies. In contrast, the unemployment rate is affected only by *net* flows and is hence unaffected by the rate at which a filled vacancy hires an unemployed worker as an employed worker is simultaneously displaced into unemployment in such an event, giving rise to no change in the unemployment pool on net.

Using data from the Current Population Survey (CPS) on employment, unemployment and short term unemployment, we find, for the period 1990m1-1999m12, the average monthly exit probability of an employed individual is about 0.032 while the average monthly job finding probability of an unemployed individual is given by 0.44. Over the same time period, we use data from Fallick and Fleischman (2004), and find a EE probability of 0.027. Using information from the SIPP, we find a layoff-to-quits ratio of 0.17 over the same time period. For the period post-2000, we find, using the same datasets, an average monthly exit probability of 0.023, an EE probability of 0.019, and a layoff-to-quits ratio of 0.28.

Table 1: Model Parameters

Fixed Parameters			
Parameter	Value	Description	
ρ	0.004	Discount rate	
η	0.72	Bargaining weight	
α	0.50	Elasticity on matching function	
Calibrated Parameters (1990-1999)			
Parameter	Value	Targets	Model Moment
λ_f	0.16	Layoff-to-quits ratio of 0.17	0.18
λ_w	0.39	EE probability of 0.027	0.029
δ	0.03	EU probability of 0.032	0.035
χ	1.50	Unemployment rate of 0.05	0.050
b	0.70	70% UI ratio	0.65
σ_x	0.09	UE probability of 0.44	0.41
Calibrated Parameters (post-2000)			
Parameter	Value	Targets	Model Moment
λ_f	0.18	Layoff-to-quits ratio of 0.28	0.28
λ_w	0.37	EE probability of 0.019	0.019
δ	0.02	EU probability of 0.023	0.023
χ	3.46	Unemployment rate of 0.05	0.054

Table 1 summarizes our calibrated parameters. Over the two time-periods, λ_f increased while λ_w decreased, in line with the empirical findings of a declining EE rate and a higher layoff-to-quits ratio. δ declined across the two time periods, in line with the decline in EU probabilities over time. A higher λ_f and lower in δ, holding θ constant, raises the value of vacancy creation, as the former raises the opportunity of finding a better worker while the latter increases the longevity of a vacancy. For unchanged χ, this would incentivize firms to post more vacancies leading to lower unemployment. Since we target a constant unemployment rate, this necessitates an increase in χ in the second time-period, which counters the incentive to create more vacancies. Overall, from the lens of our model, the firm's ability to conduct OJS, as measured by $\lambda_f q$, rose by 24% in the post 2000 period, even though λ_f only increases by around 8%. Conversely, the worker's ability to conduct on-the-job search, as measured by $\lambda_w p$, fell by 23% over the same time period (even though λ_w only falls by around 7%).

Non-targeted moments While our model matches the targeted moments well, it also does a fairly good job at matching non-targeted moments. The first non-targeted moment we consider is net employment growth. Empirically, net employment growth, defined in the QWI as the difference between firm job gains and firm job losses, declined by 95% across the two time periods. Our model accounts for two-thirds of this decline.[20] Next, Hyatt and Spletzer (2016) show that the tenure distribution has shifted towards longer tenure jobs: the median job duration has gone up by about one full year from 3.5 years in 2000 to 4.6 years in 2012-2014. Our model predicts that average tenure would have lengthened by about 10 months, close to its empirical counterpart.[21] Figure 5 shows our model's predicted

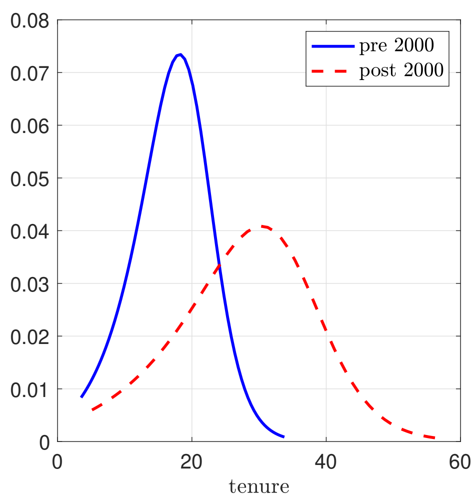


Figure 5: Model Predicted Tenure Distribution

rightward shift in the tenure distribution, consistent with the fact that average tenures have increased over time across the two time periods. Hyatt and Spletzer (2016) also report that the lengthening in job has been accompanied with a decline in the returns to tenure. As we show in Section 5.1.1, a lower pass-through from productivity to wages allows our model to jointly account for longer tenure duration

[20]Since job gains in data is measured as $\mathbb{I}(\text{Hires } - \text{Replacement Hires}) > 0$, we measure job gains in our model as hiring by unfilled vacancies only. Separately, job losses in our model stem from both endogenous worker separations, $p^*(x)$, and from exogenous destruction which occurs at rate δ.

[21]In our model, the rate at which a firm-worker pair of quality x separates is given by job end rate of $x = p^*(x)+q^*(x)+\delta$. We convert this into a monthly probability by computing job end probability of $x = 1 - \exp(-\text{job end rate of } x)$ and calculate the tenure duration as the inverse of the probability that a job ends. We then aggregate across all x values to derive average tenure.

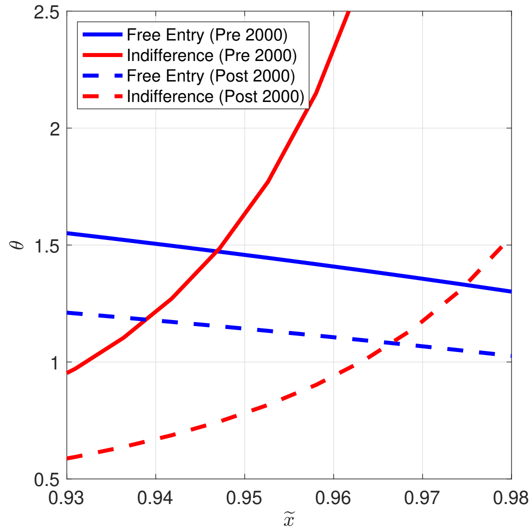


Figure 6: $\widetilde{x}$ and θ in Pre- and Post 2000 period

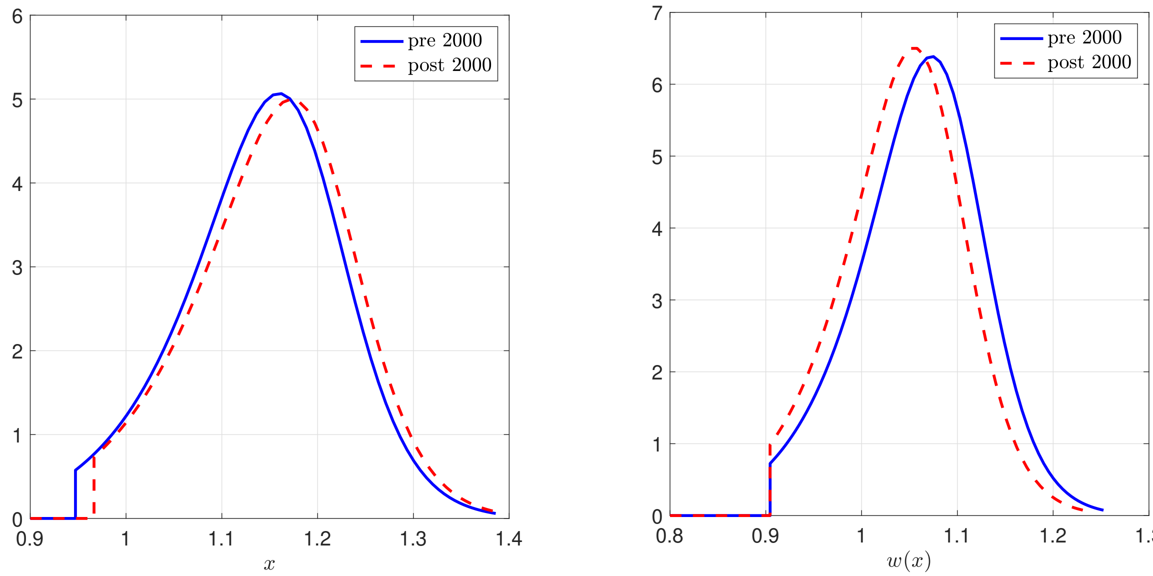
alongside a decline in the returns to tenure. Finally, across the two time periods, our model predicts that the replacement hiring share increased by 40%, relative to a rise of 22% observed in data.[22] In part, our model's larger increase in the replacement hiring share reflects the fact that firms are longer-lived (δ falls), allowing them more opportunities to either replace incumbent workers with better applicants, or to refill vacated positions. Separately, the rise in $\lambda_f q$ allows firms a greater ease of conducting OJS, further contributing to our model-predicted rise in the replacement hiring share.

5.1.1 Model Implications for Productivity-Wage Gap

We now use our calibrated model to examine changes in the productivity-wage gap. Table 2 shows our results. As aforementioned, the general equilibrium effects of a change in the ease of worker and firm OJS depends on how these changes affect the equilibrium reservation match quality and labor market tightness, $(\widetilde{x}, \theta)$. Figure 6 shows how the free-entry curve shifted downward in the second time period while the worker indifference-condition shifted outward, causing $\widetilde{x}$ to rise and θ to fall. A decline in λ_w causes the worker indifference locus (18) to shift out from the solid-red to the dashed-red curve in Figure 6. Intuitively, for the same market tightness, a lower λ_w makes it harder for employed workers to find better jobs. Consequently, unemployed workers hold out for better productivity jobs. A higher λ_f also implies that firms can search on-the-job more easily, increasing the likelihood that the firm can replace its current worker with a better match. This, too makes unemployed workers raise the threshold of match-productivity of the job they accept, so as to lower the probability of getting replaced.

In contrast, given χ, a lower λ_w, a lower δ and a higher λ_f, all tend to make posting a vacancy more attractive, pushing the free-entry curve (17) outwards. However, as mentioned earlier, since we target a constant unemployment rate across the two time periods, the increase in χ counters this increased

[22]Since a period in our model is a month while the replacement hiring share in data is recorded at a quarterly frequency, we time-aggregate our model-generated data to derive a quarterly replacement hiring share. This quarterly time aggregation captures replacement hires conducted both for the purposes of re-filling a vacated position when a worker conducts OJS as well as for firm OJS reasons.



(a) Productivity Distribution

(b) Wage Distribution

Figure 7: Model-implied Productivity and Wage Distribution

value of posting a vacancy and results in the free-entry curve moving inwards, depicted by the shift from the solid-blue to dashed-blue curves in Figure (6). The net effect is that the post 2000 period is characterized by a higher $\widetilde{x}$ and a lower θ. The higher $\widetilde{x}$ leads to a rightward shift in the equilibrium match-quality distribution, as depicted in Figure 7a. This in turn results in a higher labor-productivity in the post 2000 period of about 1 percent, as shown in Table 2.

While there are more higher quality matches in the post 2000 period, the wage distribution observes a larger share of workers earning lower wages, as can be seen in Figure 7b. Thus, although labor productivity rose over the two time periods, the average wage in the economy fell by 1%. The lower wages are reflective of weaker workers' outside options (lower ρU). Intuitively, a greater ease of firm OJS allows them to more easily replace incumbent workers with better applicants. Even if overall separation rates decline because of the fall in δ, increased firm OJS still raises the rate at which workers are endogenously displaced into unemployment. This increased *job insecurity* lowers the value of employment, and hence ρU. To see this, we construct a measure of job insecurity as the fraction of exits into unemployment that arise from endogenous separations:

$$\text{job insecurity} \;=\; \frac{\int_{\widetilde{x}}^{\overline{x}} q^*(x)dF(x)}{\int_{\widetilde{x}}^{\overline{x}} q^*(x)dF(x)+\delta},$$

Our calibration suggests that the fraction of exits into unemployment stemming from firm OJS rises by 45% across the two time periods. This increased job-insecurity reflects the rise in the fraction of vacancies that are actually firms conducting OJS, i.e., $\lambda_f v^m/v$. Precisely because workers are more likely to enter into unemployment for the reasons of being replaced by a better applicant, this has a negative effect on ρU.

Further, a greater ease of firm OJS alongside a decline in worker OJS lowers *measured-matching-*

efficiency, which is the gap between the meeting and hiring rates for unemployed workers, and is thus also the probability with which an unemployed worker is hired conditional on meeting a firm. Both a rise in firm OJS and a decline in worker OJS tilt the composition of vacancies towards filled firms. Since a filled firm only hires an applicant who draws higher productivity than its incumbent worker, this change in the composition of vacancies towards filled firms lowers the rate at which workers leave unemployment. Consequently, a decline in measured matching efficiency also works towards reducing ρU. In our model, measured matching efficiency is computed as:

$$\text{measured-matching-efficiency} = \frac{v^u}{v}[1 - \Pi(\widetilde{x})] + \frac{\lambda_f v^m}{v}\int_{\widetilde{x}}^{\overline{x}} [1 - \Pi(z)] dF(z)$$

As aforementioned, $\lambda_f v^m/v$ rises by 45%, making it more likely for unemployed job-seekers to encounter firms conducting OJS. Consequently, measured matching efficiency falls by 28%. In summary, both higher job insecurity and lower measured-matching-efficiency cause ρU to fall, lowering the average wage in the economy despite better matches being formed.

Table 2: Equilibrium Outcomes

Pre vs. Post 2000		
	description	Percent change
$\widetilde{x}$	reservation productivity	2.0
θ	labor market tightness	-32
$\lambda_f q$	firm OTJ contact rate	24
$\lambda_w p$	worker OTJ contact rate	-23
Y/N	labor productivity	1.0
mean w	average wage	-1.0
ρU	worker outside option	-1.4
job insecurity	fraction of EU that is endogenous	45
$\lambda_f v^m/v$	fraction of vacancies firm OJS	45
matching efficiency	measured matching efficiency	-28
$\int_{\widetilde{x}}^{\overline{x}} w'(x)dF(x)$	average pass-through	-3.1
$\frac{Y/N}{\text{mean} w}$	productivity-wage gap	1.9

The rise in labor productivity alongside a decline in average wages imply that in our model, the productivity-wage gap widens by about 2 percent, accounting for about a quarter of the rise observed in data. Thus, even accounting for general equilibrium effects on θ and $\widetilde{x}$, the prediction of equation (27) remains true: an increase in λ_f and a decline in λ_w tend to decrease the pass-through from productivity to wages, widening the productivity wage gap. In fact, the average pass-through from productivity to wages in the model, as measured by $\int_{\widetilde{x}}^{\overline{x}} w'(x)dF(x)$, declines by about 3%.

In summary, our model predicts that across the two time periods, firms and workers have seen their ease of conducting on-the-job search rise and decline, respectively. This in turn causes a smaller degree of pass-through from productivity to wages, giving rise to on average lower wages, despite greater formation of higher quality matches. Overall, our model accounts for one-quarter of the widening of the productivity-wage gap observed in data.

6 Discussion

Changes in λ_f and λ_w Thus far, we have treated λ_f and λ_w as reduced form parameters that capture the ease of firm and worker OJS. One can think of these parameters as stand-ins for how the contractual term-length of a job has changed over time. The recent rise in non-compete contracts which acts toward reducing the ease of worker OJS and would be captured in our model by a falling λ_w over time.[23] At the same time, a greater use of at-will employment contracts or contract workers by firms would imply higher job insecurity to workers. Recent work by Katz and Krueger (2019) shows that the percentage of individuals employed in non-standard work arrangements grew by about 5.1 percentage points between 2005 and 2015.[24] Notably, contracted workers represented the fastest growing segment amongst non-standard work arrangements. The higher job insecurity implied by the greater usage of contract workers would in our model be captured by a higher λ_f relative to λ_w as job insecurity is defined as the fraction of exits into unemployment that are triggered by a firm replacing a worker. Implicitly, the reciprocal of λ_f captures the term-length where the firm is restricted from firing the worker.[25] Hence, when λ_f is higher relative to λ_w, the worker is more likely to be displaced into unemployment for reasons of firm OJS. Thus, a higher λ_f relative to λ_w can be thought of as capturing the increased ease of firm OJS through the higher usage of contract workers as well as the depressed ability of workers to conduct OJS because of the coincident rise of non-compete contracts.

Wage Determination We assume that wages are determined via Nash Bargaining and that firms (workers) must leave their incumbent workers (firms) prior to bargaining with their new applicants (employers). The results in our paper would not qualitatively change if we had instead assumed a different wage determination protocol such as that of sequential auctions as in Cahuc et al. (2006). Note that in this case, matched workers leave their incumbent firm whenever the vacancy contacted offers the worker a value larger than what its incumbent firm can offer to retain her. Similarly, matched firms leave their incumbent worker whenever the applicant they meet gives the firm a larger surplus than what it can observe with its current worker. For matches where the vacancy contacted cannot counter the incumbent firm's highest offer, the offer from the vacancy contacted can still be used to bump up the worker's outside option and to renegotiate wages upward. In the same vein, when the firm does OJS and contacts an applicant who cannot counter its incumbent worker's highest offer to retain the firm, the potential match with the new applicant can be used to renegotiate the incumbent worker's wage down. As such, the prospect of firm OJS still promotes a widening productivity-wage gap. In our Nash bargaining protocol, this works through lowering workers' outside options. In the sequential auctions framework, it additionally comes through renegotiating incumbent workers' wages down. The incidence of replacement hiring may differ under the two different wage setting protocols, since replacement hires would only occur in the sequential auctions framework when the new match surplus is greater than each agent's current surplus from their existing matches.

[23] Recent work by Shi (2023) shows that 64% of executives in public firms are subject to non-compete contracts.

[24] Non-standard work arrangements include individuals who are contract workers, temporary help agency workers, on-call workers and independent contractors.

[25] In other words, if a firm commits to hiring a worker for 2 years, he cannot replace the worker within the two years although he can do so if he continues to hire the worker after the first 2 years.

We have also assumed in our model that workers and firms must leave their current partners before forming a new match and moving to the bargaining stage. We do this because the bargaining set becomes non-convex if agents are allowed to use their current matched value as their outside option, and the axioms under which Nash Bargaining is defined do not hold.[26] Our results, however, would still apply if we considered a model where wages were determined via an exogenous surplus splitting rule. This implies that the wages delivered by the firm require it to pay workers their outside option and a fixed share of the surplus. In addition, we now allow matched workers and firms to use their current matched value as their outside option whenever they contact a new vacancy or applicant. In this environment, our result that a higher incidence of firm OJS would lead to a larger productivity-wage gap still applies. Even if workers could use their current employment values as their outside option, a higher incidence of firm OJS reduces the worker's employment spells and hence their employment value. The lower employment value/outside option in turn depresses the wage the worker takes home. Thus, qualitatively, our results do not depend on the wage-setting rule we have used.

Vacancy duration and the relevant measure of market tightness The standard DMP model assumes that vacancies expire instantaneously, implying that only the current flow of vacancies are relevant for computing market tightness. In contrast, we argue that our assumption of long-lived job positions better accords with how the data on job openings is collected. In particular, the Bureau of Labor Statistics (BLS) which conducts the monthly JOLTS states that the information it collects on job openings are "a stock,or point-in-time, measurement for the last business day of each month".[27] Further, our measure of vacancies is *not* inconsistent with the JOLTS definition of a job-opening. Specifically, JOLTS requires a job opening to satisfy three criteria: 1) a position exists, 2) work can start in 30 days, and 3) the firm is actively recruiting where active recruiting implies that the firm has undertaken "steps to fill a position". Firms who conduct OJS in our model satisfy these three conditions. Our model calls to attention that the proportion of unfilled vacancies in addition to labor market tightness are important for rationalizing job-finding rates.

Restructuring The QWI does not have information by occupation. As such, one concern may be that firms who re-structure lay-off their current workers whose skills may not be suited for tasks under their new production process. In other words, one cannot observe from the data if the firm, when conducting a replacement hire, is hiring a new applicant for the same position. We argue that while we cannot directly observe this, our model does have implications for how wages would grow. To see this, consider the following example. Suppose the firm used to hire janitors but then decided to re-structure and fire all its janitors and replace them with engineers. Here, the growth rate in wages would be given by the percent difference between the average wage of engineers and the average wage of janitors. In this case, such re-structuring suggests a large change in wage growth as firms swap out their work-force with workers who perhaps better complement their new production processes. In contrast, our model has a different implication for how wages would grow if instead firm OJS is active and firms were replacing their incumbents with higher quality applicants. In particular, when firm OJS is active, it leads to

[26] See Shimer (2006) for more information.

[27] See the JOLTS chapter of the "BLS Handbook of Methods". https://www.bls.gov/opub/hom/pdf/homch18.pdf

a gentler slope of the wage function with respect to changes in productivity. Thus, our model with its implications on how wages grow with changes in productivity can be used to distinguish whether restructuring or firm OJS is active.

Additional hiring costs Our paper assumes a fixed cost of creating job positions and abstracts from other hiring costs. Adding a hiring cost paid at the time of matching would not qualitatively change the predictions of our model; it would only serve to raise hiring thresholds. So long as the replacement hiring share increases, this will still drive a larger productivity-wage gap. Moreover, the one time fixed vacancy posting cost χ, rather than the standard flow cost of a vacancy, can be interpreted as the cost of maintaining a human resources department for the duration of the job position and therefore subsumes the additional costs that could have been incurred at the time of matching.

7 Conclusion

We document that the replacement hiring share in the US has risen over time alongside a widening productivity wage-gap. We develop a model that incorporates both worker and firm OJS and examine the implications that worker vs. firm OJS has for productivity and wages. We find that, holding all else constant, both firm and worker OJS cause productivity to increase as workers and firms climb the ladder for better matches. However, the extent to which productivity is passed-through to wages depends critically on how easily firms vs. workers can conduct on-the-job search. When firms can replace workers more easily, the effective outside option of the firm is elevated relative to workers, allowing them to pass-through a smaller share of productivity to wages and consequently, widening the productivity-wage gap. Quantitatively, our calibrated model can account for one-quarter of the divergence.

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Appendix

A Additional Data Work

In this section, we clarify why the replacement hiring share is not equivalent to either the replacement hiring rate or churn. We also provide results from a shift-share analysis which suggest that the "within" component accounts for the bulk of the increase in the replacement hiring share. We also show that the rise in the replacement hiring share is broad-based and not limited to a few industries' experience. Finally, we provide information on the relatioonship between the productivity-wage gap and the replacement hiring share, the sign of which depends on whether firm or worker OJS is more prevalent.

A.1 Examining Replacement Hires

The replacement hiring share is *not* equivalent to the replacement hiring rate: the denominator in the latter is total employment while in the former it is hires. Figure 8a plots the replacement hiring rate against the hiring rate over time. The hiring rate is defined as the ratio of total hires to total employed while the replacement hiring rate is given by the ratio of replacement hires to total employed. Figure 8a highlights that higher replacement hiring share is a result of hires declining faster than replacement hires. The replacement hiring share is also not equivalent to churn in the economy which, following

(a) Replacement vs. total hiring rate

Burgess et al. (2000), is defined as total worker flows (hires plus separations) in excess of job flows (hires minus separations). Churn rates at time t are then given by:

$$\text{Churn}_t = \frac{\text{Worker Flows}_t - \text{Job Flows}_t}{0.5(\text{Emp}_t + \text{Emp}_{t+1})} = \frac{\text{Hires}_t + \text{Separations}_t - (\text{Hires}_t - \text{Separations}_t)}{0.5(\text{Emp}_t + \text{Emp}_{t+1})} = \frac{2 \times \text{Separations}_t}{0.5(\text{Emp}_t + \text{Emp}_{t+1})}$$

Since replacement hires are only a subset of all separations, they are a fraction of total churn.

A.2 Shift Share Analyses

To see if compositional changes in sectors are the primary factor behind the rise in the replacement hiring share, we conduct a shift-share analysis. In examining whether compositional changes were behind the rise in the replacement hiring share, we cut the data separately by firm age, firm size, by industry and by worker education. Data by firm age and size, and by worker education are only reported for private firms in the QWI. We follow the firm age and size, and worker education categories as provided by the QWI. For the shift share analysis done at the industry level, we use information available at the 2 digit NAICS level.

Because the divergence in the productivity-wage gap largely occurred after the 2000s, we divide the periods into pre-2000 and post 2000, and take the mean of the replacement hiring share in these two periods. We weight each firm age/size/industry/worker education category by their average employment share. Across the two time periods, the average replacement hiring share rose by about 3 percentage points. To assess how much of the increase in the replacement hiring share can be accounted for by compositional changes ("between") vs. by just an increase within each firm age/size/industry/worker education category, we use the following decomposition:

$$\Delta \text{Replacement Hiring Share} = \sum_{it} \Delta\left(rr_{it} \frac{emp_{it}}{emp_t} \right) \approx \underbrace{\sum_{it} \widehat{rr} \Delta \left(\frac{emp_{it}}{emp_t} \right)}_{\text{between}} + \underbrace{\sum_{it} \Delta rr_{it} \widehat{\left(\frac{emp_i}{emp} \right)}}_{\text{within}}$$

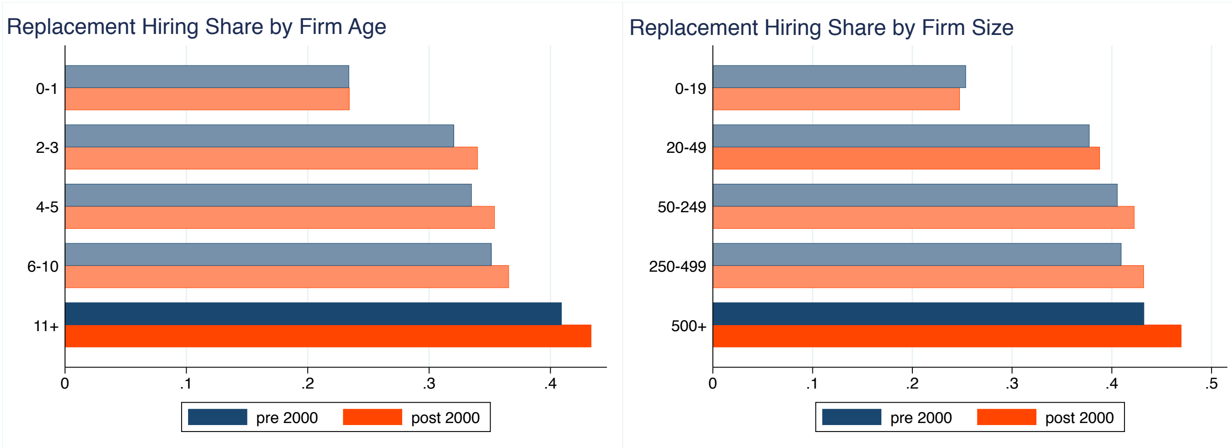
where Δ refers to the change, rr_{it} denotes the replacement hiring share of firm age/size/industry category i in period t, and emp_{it} denotes the employment in category i in period t. Terms with a "hat" denote averages. Table 3 shows the results from our shift share analysis:

Table 3: Shift-Share Analysis

Percent Explained by	Between	Within
By Firm Age	19.9%	80.1%
By Firm Size	26.7%	73.4%
By Industry	-0.0%	100%
By Worker Education	-2%	102%

A few things are noteworthy. Firstly, across firm age and size, we find that large and older firms were more likely to conduct replacement hiring. This is consistent with the notion that once firms reach their optimal firm size, they conduct replacement hires either for the purposes of finding a better worker or for the purposes of re-filling a position. Figures 9a and 9b show how replacement hiring shares vary across firm age and size for the two time periods.

Given then large and older firms are more likely to conduct replacement hiring, Our shift-share analyses reveal that compositional changes towards older and larger firms can only explain 20% and 27% of the total change in the aggregate replacement hiring share respectively. While compositional changes at the firm age and firm size level contribute partially to the increase in the replacement hiring share, Table 3 highlights that a significant bulk of the increase in the replacement hiring share stems



(a) By Firm Age (b) By Firm Size

Figure 9: Replacement Hiring Shares by Firm Age and Size

from changes within each firm age/size/industry/worker education category. This result is particularly stark at the industry and the worker education level. Focusing first on industries, Figure 10 shows that this is largely because the ranking of industries by employment share has not significantly changed, with the top 5 industries in the pre 2000 and post 2000 being exactly the same. In fact, our shift share analysis actually suggests that the change in industry composition actually contributes towards reducing the replacement hiring share by 0.005 points as opposed to increasing it.

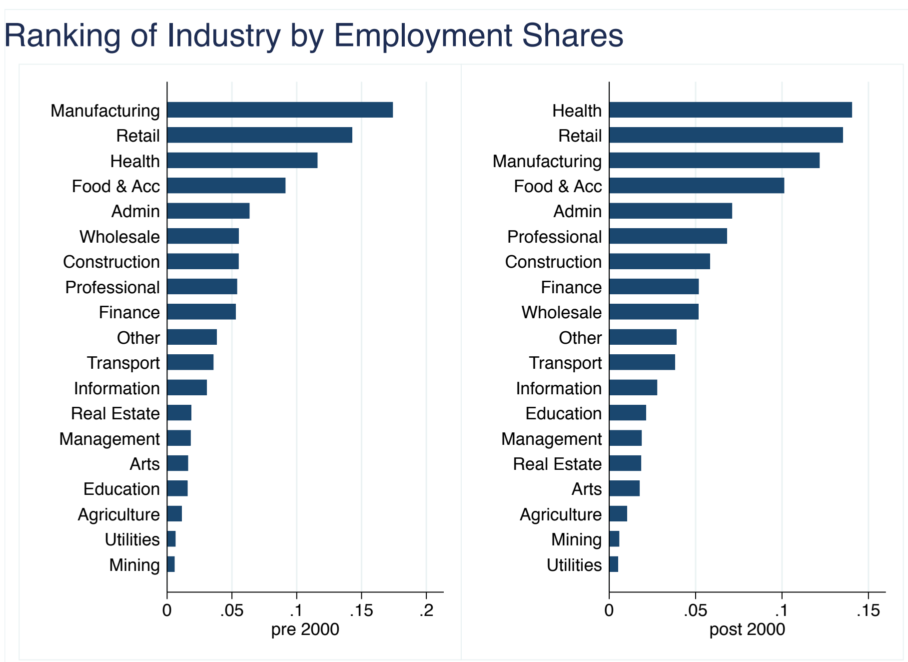


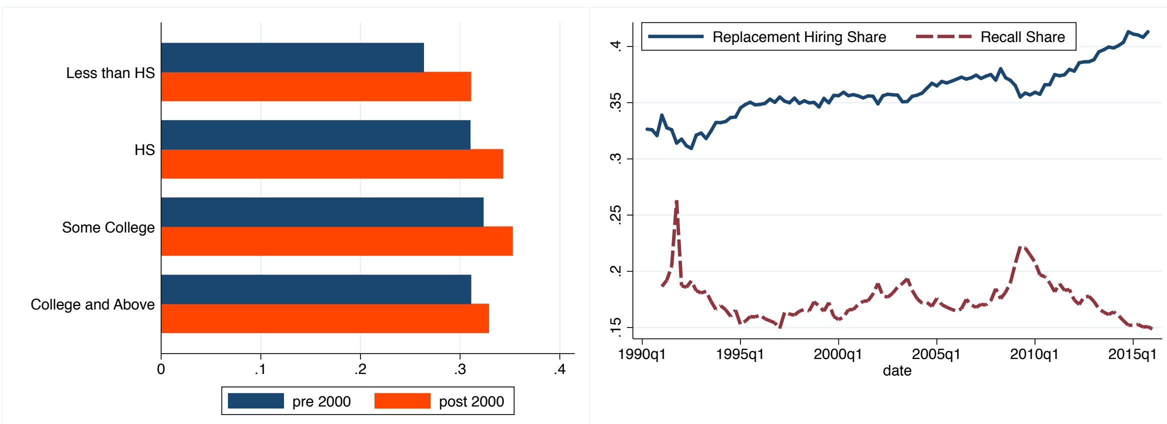
Figure 10: Ranking of industries roughly the same

Looking next at the changes by worker composition, Figure 11a shows that the replacement hiring share increased within each worker education category. Note that in these measures, the information

Table 4: An Example of Recalls and Replacement Hires

	$t-2$	$t-1$	t
A	1	0	1
B	0	1	0
Replacement hires at t			2
Recall hires at t			1

presented here is that for a hire at a firm, the firm knows the worker's education level. Thus, the following replacement shares represent the fraction of hires for individuals with a certain education level that are replacement hires. We, however, do not know if the replacement hire recorded was for a position that required the same education level. Across the two time periods, we find that changes in the between component would have reduced the replacement hiring share by 2%, highlighting that the increase in the replacement hiring share *within* each education category explains the overall rise.



(a) Replacement Hiring by Education

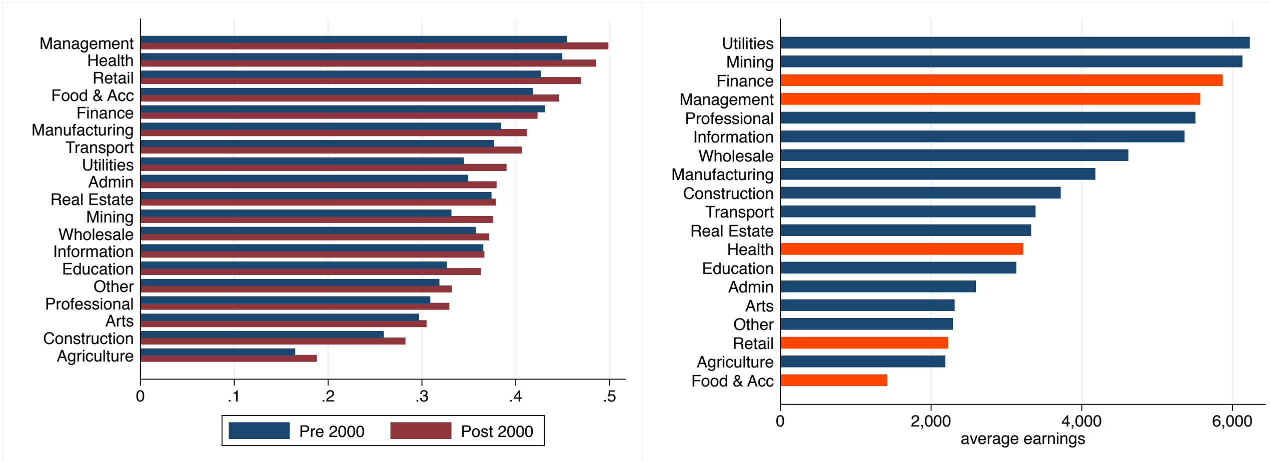
(b) Recall vs. Replacement Hiring Share

Figure 11: Replacement Hiring Share by Education and Replacement Hiring Share vs. Recall Share

A.3 Recalls vs. Replacement Hires

Finally, we examine if the replacement hiring share could be explained by recalls. In reality, some replacement hires may be recalls. To see this, consider a firm who had a worker A in period $t-2$, but worker A was temporarily laid off in period $t-1$, while worker B was hired in period $t-1$. Worker B then left the firm in period t and worker A was recalled in period t. In this example, the net employment change at the firm in periods $t-1$ and t were zero, there was one replacement hire each in period $t-1$ and t, and the replacement hire in period t was also a recall hire. This example illustrates how some replacement hires can be recall hires.

The QWI also provides information on the number of recall hires at an establishment. A recall hire is recorded whenever an individual i has earnings at establishment j in period t, had no earnings at j in period $t-1$ but recorded earnings at j in any previous period $t-2, t-3$ or $t-4$. We compute the recall share of hires as the ratio of recall hires to total hires and plot the recall hiring share against the replacement hiring share in Figure 11b. Figure 11b shows that while the recall hiring share rose during



(a) Replacement Hiring Share by Industry (b) Average Monthly Earnings by Industry

Figure 12: Replacement Hiring and Earnings by Industry

the Great Recession (an observation also documented by Fujita and Moscarini (2017) using data from the Survey Income and Program Participation (SIPP), its rise was not permanent. In the aftermath of the Great Recession, the recall hiring share fell suggesting that the rise in the replacement hiring share is not explained by an increase in recall hiring.

A.4 Replacement Hiring Across Industries and Earnings

To examine if industries with low average earnings are responsible for the high replacement hiring share, we use the industry aggregated information from the QWI on the average monthly earnings of employees who worked with the same firm throughout the quarter and compare whether the industries who have high replacement hiring share also have low average earnings. Figure 12a highlights that most industries observed an increase in their replacement hiring share post 2000 and that the top five industries which have a high share of replacement hiring are Management of Companies and Enterprises, Healthcare and Social Assistance, Retail Trade, Accommodation and Food Services and Finance and Insurance. Figure 12b highlights that these top five industries by replacement hiring share (shaded in orange) are not exclusively low-paying industries. In fact, both Management of Companies and Enterprises and Finance and Insurance appear at the upper end of the average earnings distribution. The high replacement hiring share prevalent in these industries suggest that not all replacement hires occur to refill positions vacated by workers in low-paying industries with high turnover.

A.5 Labor shares, earnings and pass-through

We now turn to showing how the productivity wage-gap can be affected by firm OJS. While we do not have direct measures of firm OJS, as aforementioned, the way firm OJS manifests is through replacement hiring. As such, our analysis below will focus on the sign associated with replacement hiring shares.

One implication from our model is that when firms engage in more OJS relative to worker OJS, the pass-through of productivity to wages is lower. To support this hypothesis, we investigate whether the productivity wage-gap within an industry systematically varies with its replacement hiring share. When worker OJS is the primary reason for replacement hires, then industries with higher replacement hiring shares should observe lower productivity-wage gaps, as workers' outside options and thus, bargaining positions, are elevated by their ease of switching jobs. We test whether such a negative relationship exists by utilizing data from the NBER-CES Manufacturing Industry Database.[28] This database provides information on the value-added, payroll, employment and TFP of manufacturing industies at the six digit NAICs code level. We use information on payroll and employment to construct a measure of labor share, and use the reciprocal of the labor share as our measure of the productivity-wage gap in each industry. Combining this information with data on replacement hiring shares from the QWI, we regress labor share against replacement hiring at the industry-quarter level. We include industry fixed effects in our regression.

The positive relationship between the productivity-wage gap and the replacement hiring share is not just a feature of the aggregate time-series; this relationship also holds in the cross-section. Column I of Table 5 shows that industries with a wider productivity-wage gap tend to have higher replacement hiring share. The positive relationship between the productivity-wage gap and replacement hiring share suggests that worker OJS may not be the primary reason behind replacement hiring and that firm OJS may be a key factor driving the divergence in productivity and wages.

Table 5: Productivity-wage gap and Pass-through

	Dependent Variable		
	Productivity-wage gap	Δ Log Earnings	
	I	II	III
Replacement hiring share	6.18^{***}	-0.07^{***}	-0.13^{***}
	(0.73)	(0.02)	(0.02)
Δ Log labor productivity	-	0.26^{***}	-
	-	(0.06)	-
Δ Log labor productivity × repl. hiring share	-	-0.32^{**}	-
	-	(0.10)	-
Δ Log TFP	-	-	0.32^{***}
	-	-	(0.12)
Δ Log TFP × repl. hiring share	-	-	-0.59^{**}
	-	-	(0.28)
Industry Fixed Effects	Y	Y	Y
N	1891	1805	1805
R^2	0.04	0.18	0.04
F-stat	70.86	126.53	23.54

Similarly, we examine whether the pass-through from productivity to wages varies positively with replacement hiring. For our measure of productivity, we use information on value-added and employment to construct measures of value-added per person at the industry level. We term value-added per person labour productivity. We regress the change in log earnings against the change in log labor productivity, the replacement hiring share as well as an interaction term of the change in log labour productivity times the replacement hiring share. The term of interest is the coefficient on the interaction term between the

[28] https://www.nber.org/research/data/nber-ces-manufacturing-industry-database

growth in labour productivity and the replacement hiring share. Implicitly, wages would grow faster with improvements in labor productivity if worker OJS is the primary reason for replacement hiring. Thus, we would expect a positive coefficient on the interaction term of productivity with replacement hiring share. We instead find the opposite, as documented in Column II of Table 5 . Running the same regression on the growth in earnings against the growth rate of log TFP and interaction term of the latter growth rate with the replacement hiring share, we find similar results as shown in Column III of Table 5. Our results suggest that firm OJS is a non-trivial factor behind replacement hiring and the widening of the productivity-wage gap.

B Surplus, Wages and Distribution of Matched Firm-worker Pairs

Recruiting firm-worker pair Subtract (4) from (1) and rearrange to get the firm's gain to matching:

$$(\rho+\delta+q^{*}(x)+p^{*}(x))\left[J(x)-\chi\right]=x-w(x)-\left[(\rho+\delta)\chi-\widehat{R}(x)\right] \tag{28}$$

where

$$\begin{aligned}\widehat{R}(x) &= \lambda_f q\frac{u}{\ell}\int_{x}^{\overline{x}}\left[J(y)-J^{u}\right]d\Pi(y)\\ &+\lambda_f q\frac{\lambda_w v^{m}}{\ell}\left\{\int_{x}^{\overline{x}}\left[J(y)-J^{u}\right]d\Pi(y)F(x)+\int_{x}^{\overline{x}}\int_{\epsilon}^{\overline{x}}\left[J(y)-J^{u}\right]d\Pi(y)\,dF(\epsilon)\right\}\end{aligned}$$

Observe that $(\rho+\delta)\chi-\widehat{R}(x)$ represents the firm's effective outside option. The firm's effective outside option or relative gain from continuing to search as an unfilled vacancy is the higher meeting rate q and all the possible matches from $\widetilde{x}$ to x. Next, subtracting ρU from both sides of (8) yields us the worker's gain to matching:

$$(\rho+\delta+q^{*}(x)+p^{*}(x))\left[W(x)-U\right]=w(x)-\left[\rho U-\widehat{H}(x)\right] \tag{29}$$

where

$$\begin{aligned}\widehat{H}(x) &= \lambda_w p\frac{v^{u}}{v}\int_{x}^{\overline{x}}\left[W(y)-U\right]d\Pi(y)\\ &+\lambda_w p\frac{\lambda_f v^{m}}{v}\left\{\int_{x}^{\overline{x}}\left[W(y)-U\right]d\Pi(y)F(x)+\int_{x}^{\overline{x}}\int_{\epsilon}^{\overline{x}}\left[W(y)-U\right]d\Pi(y)\,dF(\epsilon)\right\}\end{aligned}$$

Observe that $\rho U-\widehat{H}(x)$ is the worker's effective outside option. It represents all the foregone potential matches from $\widetilde{x}$ to x the worker could have undertaken if she chose to continue to search as an unemployed worker. Adding the two expressions and re-arranging gives us surplus:

$$\begin{aligned}\varrho(x)S(x) &= x-\rho U-(\rho+\delta)\chi+\left[q(1-\eta)\frac{\lambda_f u}{\ell}+p\eta\frac{\lambda_w v^{u}}{v}\right]\int_{x}^{\overline{x}}S(y)\,d\Pi(y)\\ &+q\frac{\lambda_f\lambda_w v^{m}}{\ell}\left\{\int_{x}^{\overline{x}}S(y)\,d\Pi(y)F(x)+\int_{x}^{\overline{x}}\int_{\epsilon}^{\overline{x}}S(y)\,d\Pi(y)\,dF(\epsilon)\right\}\end{aligned} \tag{30}$$

where $S(x) = J(x) - J^u + W(x) - U$ and $\varrho(x) = \rho + \delta + p^*(x) + q^*(x)$. Next using the Nash Bargaining solution (12), the free entry condition (i.e. equation 4) can be re-written as:

$$(\rho+\delta)\,\chi = (1-\eta)\,q\left[\frac{u}{\ell}\int_{\widetilde{x}}^{\overline{x}} S\,(y)\,d\Pi\,(y) + \lambda_w\frac{1-u}{\ell}\int_{\widetilde{x}}^{\overline{x}}\int_{\epsilon}^{\overline{x}} S\,(y)\,d\Pi\,(y)\,dF\,(\epsilon)\right]$$

Evaluating (30) at $\widetilde{x}$ and plugging for free-entry, we get equation (18).

B.1 General Wage Form

Note from the worker's gain to matching, we have:

$$(\rho+\delta+q^*\,(x)+p^*(x))\,\eta S\,(x) = w\,(x) - [\rho U - \widehat{H}(x)]$$

Using the form of $\widehat{H}(x)$ and making $w(x)$ the subject of the equation, we have:

$$\begin{aligned} w\,(x) &= \eta x + (1-\eta)\,\rho U - \eta\,(\rho+\delta)\,\chi \\ &\quad + (1-\eta)\,\eta\left[\lambda_w p\frac{v^u}{v} - \lambda_f q\frac{u}{\ell}\right]\int_x^{\overline{x}} S\,(y)\,d\Pi\,(y) \end{aligned} \tag{31}$$

B.2 Distribution of productivity

Focusing on the measure of matched firm-worker pairs with match quality less than or equals to x and dividing everywhere by $v^m = (1-u)$, we get:

$$\begin{aligned} \left[q\frac{v^u}{(1-u)}\frac{u}{\ell}\right][\Pi\,(x) - \Pi\,(\widetilde{x})] &= \delta F\,(x) + qF\,(x)\,[1-\Pi\,(x)]\left[\lambda_f\frac{u}{\ell} + \lambda_w\frac{v^u}{\ell}\right] \\ &\quad + 2\lambda_f qF\,(x)\,\frac{\lambda_w F\,(x)\,(1-u)}{\ell}\,[1-\Pi\,(x)] \\ &\quad + 2\lambda_f qF\,(x)\,\frac{\lambda_w\,(1-u)}{\ell}\int_x^{\overline{x}}[1-\Pi\,(\epsilon)]\,f\,(\epsilon)\,d\epsilon \\ &\quad + \lambda_f q\frac{\lambda_w\,(1-u)}{\ell}\int_{\widetilde{x}}^{x}\int_z^{x}[\Pi\,(x)-\Pi\,(\epsilon)]\,f\,(\epsilon)\,f\,(z)\,d\epsilon dz \\ &\quad + \lambda_f q\frac{\lambda_w\,(1-u)}{\ell}\int_{\widetilde{x}}^{x}[\Pi\,(x)-\Pi\,(z)]\,F\,(z)\,f\,(z)\,dz \end{aligned} \tag{32}$$

C Comparative Statics

C.1 Worker On-the-job Search Only

C.1.1 Distribution of Matched Firm-Worker Pairs

Setting $\lambda_f = 0$, and using equation 32, we can show that the cumulative distribution of firm-worker pairs with match quality less than or equals to x becomes:

$$F(x) = \left[q\frac{v^u}{(1-u)}\frac{u}{\ell}\right]\frac{[\Pi\,(x)-\Pi\,(\widetilde{x})]}{(s+\delta+p\lambda_w\,[1-\Pi\,(x)])}$$

From the law of motion for the unemployed, we have:

$$q\frac{v^u}{1-u}\frac{u}{\ell} = \frac{\delta}{1-\Pi\left(\widetilde{x}\right)}$$

plugging this into $F(x)$, we get:

$$F\left(x\right) = \frac{\delta}{\delta + p\lambda_w\left[1-\Pi\left(x\right)\right]}\frac{\Pi\left(x\right)-\Pi\left(\widetilde{x}\right)}{1-\Pi\left(\widetilde{x}\right)}$$

C.1.2 Surplus and Pass-through

In the case where only workers can search on-the-job, i.e. $\lambda_f = 0$, the only vacancies workers can contact are unfilled vacancies, i.e. $v = v^u$. In this case, surplus of a match as given by equation (13) collapses to equation (20) which we replicate below for the readers convenience:

$$(\rho + \delta + \lambda_w p[1 - \Pi(x)])S(x) = x - (\rho + \delta)J^u - [\rho U - \widehat{H}(x)]$$

Evaluating the above equation at $\widetilde{x}$ allows us to define the worker's effective outside option to be as expressed as in (21), again replicated below for convenience.

$$\rho U - \widehat{H}(x) = \widetilde{x} - (\rho + \delta)J^u + \lambda_w p\eta\int_{\widetilde{x}}^{x} S(y)d\Pi(y)$$

Holding $\widetilde{x}$ and θ constant, the worker's effective outside option is increasing in λ_w because the worker must be increasing compensated for foregone opportunities when λ_w is higher. Further, (4) shows that as λ_w rises, the composition of job-seekers tilts towards that of employed job-seekers. This worsens the firm's value of an unfilled vacancy holding all else constant since the firm must now draw a match quality higher than the employed worker's incumbent firm before the worker agrees to form a new match. A higher λ_w, holding all else constant, reduces matching efficiency for an unfilled vacancy and thus lowers its value.

From (31), when $\lambda_f = 0$, the wage of type x also becomes

$$w\left(x\right) = \eta x + \left(1-\eta\right)\rho U - \left(1-\eta\right)\eta\lambda_w p\int_{x}^{\overline{x}} S\left(y\right)d\Pi\left(y\right) - \eta\left(\rho+\delta\right)J^u$$

Pass-through is then found by differentiating wages with respect to x which gives us back (22):

$$w'(x) = \eta + \left(1-\eta\right)\eta\lambda_w p\pi(x)S\left(x\right)$$

It is useful to note that taking the derivative of surplus, i.e. (20) with respect to x, we get:

$$-\frac{\left(1-\eta\right)\lambda_w p\pi\left(x\right)S\left(x\right)}{\rho+\delta+\lambda_w p\left[1-\Pi\left(x\right)\right]} + \frac{dS\left(x\right)}{dx} = \frac{1}{\rho+\delta+\lambda_w p\left[1-\Pi\left(x\right)\right]}$$

The above is an ODE and using the initial condition $S(\widetilde{x}) = 0$, surplus can also be expressed as:

$$S(x) = \frac{1}{(\rho + \delta + \lambda_w p[1 - \Pi(x)])^{1-\eta}} \int_{\widetilde{x}}^{x} \frac{1}{(\rho + \delta + \lambda_w p[1 - \Pi(y)])^{\eta}} dy \tag{33}$$

Plugging (33) into (22), one can show that the pass-through of productivity to wages is increasing in λ_w, ceteris paribus. Pass-through can be re-stated as:

$$w'(x) = \eta + (1-\eta)\eta \frac{1}{\left(\frac{\rho+\delta}{\lambda_w p} + \widehat{\Pi}(x)\right)^{1-\eta}} \int_{\widetilde{x}}^{x} \frac{1}{\left(\frac{\rho+\delta}{\lambda_w p} + \widehat{\Pi}(y)\right)^{\eta}} dy \pi(x) \tag{34}$$

where $\widehat{\Pi}(x) = 1 - \Pi(x)$. The equation above shows that $w'(x)$ is rising in λ_w.

C.2 Firm On-the-job Search Only

C.2.1 Distribution of Matched Firm-Worker Pairs

Shutting down worker OJS, $\lambda_w = 0$, one can show that equation 32 becomes:

$$F(x) = q \frac{v^u}{1-u} \frac{[\Pi(x) - \Pi(\widetilde{x})]}{\delta + \lambda_f q[1 - \Pi(x)]}$$

At the same time, the law of motion for the unemployed becomes:

$$q \frac{v^u}{1-u} = \frac{\delta}{1 - \Pi(\widetilde{x})}$$

Plugging the above into $F(x)$, we get that the distribution of matched firm-worker pairs with match quality $\leq x$ is given by:

$$F(x) = \frac{\delta}{\delta + \lambda_f q [1 - \Pi(x)]} \frac{\Pi(x) - \Pi(\widetilde{x})}{1 - \Pi(\widetilde{x})}$$

C.2.2 Surplus and Pass-through

With $\lambda_w = 0$, we have $u = \ell$. (30) then simplifies to (24), replicated below for convenience:

$$(\rho + \delta + \lambda_f q[1 - \Pi(x)]) S(x) = x - \rho U - [(\rho + \delta) J^u - \widehat{R}(x)]$$

Evaluating the above at $\widetilde{x}$, we arrive at the effective outside option of the firm (25), replicated again below for convenience:

$$(\rho + \delta) J^u - \widehat{R}(x) = \widetilde{x} - \rho U + \lambda_f q (1-\eta) \int_{\widetilde{x}}^{x} S(y) d\Pi(y)$$

Turning to wages and using (31), with $\lambda_w = 0$, we get

$$w(x) = \eta x + (1-\eta)\rho U + (1-\eta)\eta\lambda_f q \int_{x}^{\overline{x}} S(y)\, d\Pi(y) - \eta(\rho + \delta) J^u$$

Differentiating $w(x)$ with respect to x, we get (26):

$$w'(x) = \eta - \eta(1-\eta)\lambda_f q S(x)\pi(x)$$

Diffentiating (24) with respect to x, we have:

$$-\frac{\eta\lambda_f q\pi(x)}{(\rho+\delta+\lambda_f q[1-\Pi(x)])}S(x) + S'(x) = \frac{1}{(\rho+\delta+\lambda_f q[1-\Pi(x)])}$$

The above is an ODE with boundary condition $S(\widetilde{x}) = 0$. Solving, we arrive at (35).

$$S(x) = \frac{1}{(\rho+\delta+\lambda_f q[1-\Pi(x)])^{\eta}} \int_{\widetilde{x}}^{x} \frac{1}{(\rho+\delta+\lambda_f q[1-\Pi(y)])^{1-\eta}} dy \tag{35}$$

Plugging (35) into $w'(x)$, we get (36).

$$w'(x) = \eta - \eta(1-\eta)\pi(x)\frac{1}{\left(\frac{\rho+\delta}{\lambda_f q} + \widehat{\Pi}(x)\right)^{\eta}} \int_{\widetilde{x}}^{x} \frac{1}{\left(\frac{\rho+\delta}{\lambda_f q} + \widehat{\Pi}(y)\right)^{1-\eta}} dy \tag{36}$$

The equation above shows that $w'(x)$ is declining in λ_f.