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Labor Market Policies During an Epidemic*

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Abstract

We study the positive and normative implications of labor market policies that counteract the economic fallout from containment measures during an epidemic. We incorporate a standard epidemiological model into an equilibrium search model of the labor market to compare unemployment insurance (UI) expansions and payroll subsidies. In isolation, payroll subsidies that preserve match capital and enable a swift economic recovery are preferred over a cost-equivalent UI expansion. When considered jointly, however, a cost-equivalent optimal mix allocates 20 percent of the budget to payroll subsidies and 80 percent to UI. The two policies are *complementary*, catering to different rungs of the productivity ladder. The small share of payroll subsidies is sufficient to preserve high-productivity jobs, but it leaves room for social assistance to workers who face inevitable job loss.

Keywords: COVID-19, Fiscal Policy, Labor Productivity, Unemployment, Job Search
JEL Classification: E24, E62, J64

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1 Introduction

The ongoing COVID-19 pandemic has resulted in a rapid contraction of economic activity and a severe deterioration of labor market conditions in the U.S. To mitigate the effects of massive dislocation in the labor market, the U.S. government introduced policy measures through the Coronavirus Aid, Relief, and Economic Security (CARES) Act with an initial size of about two trillion dollars. In this paper, we study the two prominent components of this package: the expansion of unemployment insurance (UI) benefits and the introduction of payroll subsidies, and make two broad contributions. On the positive side, we analyze the differential effects of direct transfers to the unemployed through a UI benefit expansion vis-à-vis granting firms payroll subsidies to preserve matches. Taking these differential effects into account, our normative contribution answers an important question: How should the government allocate limited resources between these programs?

The two policies have distinct goals and labor market effects. The expansion of UI payments provides additional income to the large influx of job losers during the pandemic-driven downturn. In comparison, the Payroll Protection Program (PPP), which extends forgivable loans to firms, aims to prevent business closures and keep worker-firm matches intact so that when labor demand rebounds, a swifter recovery follows. A key advantage of this program is that it preserves match capital that has been formed in the labor market over many years of investment.

We analyze these policies during the pandemic and the recovery thereafter. To do so, we combine the classical epidemiological model of Kermack and McKendrick (1927) with an equilibrium search model of the labor market in Section 2. Our model consists of two sectors (essential and nonessential) with ex-ante identical, risk averse, hand-to-mouth households and risk neutral firms. The model has four features to capture key aspects relevant for policy analysis.

First, the infection probability depends on an individual's involvement in production as well as the aggregate labor supply and population of infected agents. The spread of the infection thus depends on (public) containment policies as well as (private) behavioral responses through labor supply. This allows us to study how labor market policies interact with containment measures.

Second, financial frictions and wage rigidity in the model lead to inefficient job separations. Some firms are subject to financial frictions in that per-period net profits have to remain above a threshold. If this constraint binds, the worker-firm match dissolves temporarily. In addition, downward wage rigidity implies that infection results in reduced productivity but not in lower pay. Hence, the epidemic increases the probability of inefficient separations by reducing firm surplus.

Third, the labor market features match-specific productivity that grows stochastically over time, capturing the idea that preserving long-tenure jobs is important for aggregate productivity and output. Firms have a recall option when temporary separations occur regardless of payroll protection, which allows us to discipline a policy's contribution to match preservation.

Finally, the government has two sets of policy instruments, a containment policy expressed as a tax on production, and fiscal policies: UI benefits and payroll subsidies. Our framework allows us to study their effects in isolation and solve for their optimal mix. Importantly, they are distinct because when UI is generous and payroll subsidies are absent, the severance of a match is more likely to result in permanent match dissolution as i) some firms may no longer be operational to even rehire, ii) labor market frictions may hinder rehiring, iii) workers may find new matches, and finally iv) recall rejection rates may be higher.

We calibrate the model's steady state to match key moments of the U.S. labor market prior to the epidemic (Section 3) and introduce the epidemic as a one-time unanticipated shock through a sudden infection of a small share of the population (Section 4). Concurrently, the government introduces a containment policy. The relationship between match productivity and the financial constraint determines the composition of job losses in a downturn: If more productive firms can borrow more, a larger share of match destruction occurs at low-wage jobs. We discipline this relationship using micro data on the magnitude and composition of job losses during the epidemic.

We use our model to evaluate the policy options by simulating an increase in UI generosity similar to the CARES Act and a cost-equivalent payroll subsidy. Implementing a UI expansion in isolation leads to a large rise in unemployment. Lost match capital results in persistently low average labor productivity (ALP) and output post containment, as newly formed jobs have low productivity. Payroll subsidies achieve the opposite by preserving existing matches because they allow financially constrained firms that would have otherwise engaged in layoffs to continue operating. The preservation of match capital softens the decline in employment, productivity and output, and the economy recovers faster. UI provides additional insurance to job losers who fall off the job ladder, whereas payroll subsidies preserves workers' position along the ladder. However, payroll subsidies have two drawbacks relative to UI. First, there is no direct insurance benefit to job losers. Second, while subsidies allow some firms to retain matches while idle, they also enable others to continue active production. The ensuing higher economic activity results in more infections. Comparing a UI expansion to a payroll subsidy in isolation, the former yields a welfare gain of 0.18 percent in additional lifetime consumption, while the latter yields 0.76 percent, implying that a payroll subsidy is preferred over a cost-equivalent UI expansion.

We then proceed to computing the optimal policy mix, subject to the same amount of total government spending. The optimal policy allocates 20 percent of the budget to payroll subsidies and the remaining 80 percent to UI expansion. Although payroll subsidies comprise a smaller share of spending, we show that this partial expenditure achieves most of the gains that can be obtained by allocating the entire budget on payroll subsidies. The initial marginal gains of spending on payroll subsidies are large. Thus, the optimal policy sets the payroll subsidy just enough to preserve high-productivity matches as any payments in excess yield limited marginal gains and, importantly, the optimal policy leaves fiscal space for UI payments. Increased UI generosity provides consumption insurance to workers whose jobs are not saved by payroll subsidies. With more generous UI payments, the unemployment rate rises more, but the additional decline and the slow recovery of output are completely offset through payroll subsidies that preserve high-productivity matches. Thus, the two labor market policies are *complementary*.

Different countries have implemented lockdowns of varying stringency. We show that the share of the budget allocated to payroll subsidies increases with the strictness of containment measures. A more aggressive containment policy leads to the permanent dissolution of high-productivity matches that would have survived under a more lax one, raising the importance of firm preservation, and thereby the value of payroll subsidies.

Our analysis abstracts away from at least one important margin. The COVID-19 pandemic and the containment policies have a strong sectoral component, with high-contact and nonessential jobs being disproportionately affected. Depending on how long the epidemic lasts and how persistent its effects are, it may be desirable to have some workers move away from sectors that face persistent declines. Payroll subsidies directed toward these sectors are more likely to hinder mobility and unnecessarily delay the reallocation process. Allowing for sectoral reallocation may therefore imply an even larger share of funds to be allocated for UI policies in the optimal mix than we find.

This paper contributes to the emerging literature on the economic effects of the COVID-19 pandemic (see Alvarez et al., 2020; Atkeson, 2020; Berger et al., 2020; Bick and Blandin, 2020; Brotherhood et al., 2020; Ganong et al., 2020; Garriga et al., 2020; Glover et al., 2020; Faria-e Castro, 2020b; Kurmann et al., 2020, among others). Our paper is closely related to studies that analyze the labor market effects of the epidemic. (see Alon et al., 2020; Boar and Mongey, 2020; Fang et al., 2020; Giupponi and Landais, 2020; Gregory et al., 2020; Kapicka and Rupert, 2020; Mitman and Rabinovich, 2020). Relative to this literature, we jointly study UI and payroll subsidies and analyze their differential effects on the labor market. To the best of our knowledge, this paper is the first in analyzing the trade-offs between different labor-market policies, their optimal mix, and how they interact with the strength of containment measures.

Our work also makes broader contributions to the literature that uses quantitative models to study the labor market effects of UI (Krusell et al., 2010; Nakajima, 2012; Jung and Kuester, 2015; Mitman and Rabinovich, 2015; Kolsrud et al., 2018; Landais et al., 2018; Chodorow-Reich et al., 2019; Hagedorn et al., 2019; Birinci and See, 2020) and payroll subsidies (Burdett and Wright, 1989; Tilly and Niedermayer, 2016; Cooper et al., 2017; Cahuc et al., 2018). First, we present a framework suitable for jointly studying both policies. In the model, financial frictions and rigid wages generate inefficient separations that both policies can mitigate. Crucially, we do not homogenize job separations and instead, distinguish between idle matches, temporary layoffs with a recall option, and permanent separations to capture the differential effects of UI and payroll subsidies. Second, we identify key complementarities between the two policies. To the best of our knowledge, existing work studies each of these policies in isolation and ignores their interactions.

2 An Equilibrium Labor Market Model in an Epidemic

We synthesize a basic epidemiological SIR model with an equilibrium labor search model that features match-specific productivity and recalls. We then use our model to study labor market policies proposed to lessen the economic impact of the epidemic.

2.1 The Environment

Time is discrete and runs forever. The economy is populated by a measure one of workers and a continuum of ex-ante identical firms in two sectors: essential and nonessential. Households in each sector are ex-ante identical and there is no mobility across sectors. Here, we describe the nonessential sector in detail and only outline key differences in the essential sector.

Households. Households are risk averse and differ in terms of their employment status, health status h, match-specific capital z, and wage w. A worker can be either employed W, unemployed on temporary layoff U_T, or unemployed and permanently separated U_P. Employed workers can be attached to firms that are either actively producing or idle, while workers on temporary layoff can be recalled back to their previous employers. Employed households have the option to quit and dissolve the match permanently each period. Unemployed households search for jobs and, upon contact, decide whether to accept an offer. Thus, individuals can reduce their own risk of infection by quitting from a job or refusing a new offer.

In terms of health, households are classified as either susceptible S, infected I, recovered R, or dead D. Susceptible workers can become infected by engaging in production or by meeting infected agents for reasons unrelated to economic activity, e.g. meeting an infected neighbor. Similar to Eichenbaum, Rebelo, and Trabandt (2020), we model this infection probability as

$$e_n\left(N^I, I\right) = \pi_1 n N^I + \pi_2 I, \tag{1}$$

where $n \in \{0, 1\}$ indicates if the individual is employed and actively producing; N^I is the mass of actively employed and infected workers; and I denotes the mass of infected people in the economy. Infected people recover or die at exogenous rates π^R and π^D, respectively, and the recovered have permanent immunity to the disease. These transition probabilities can be summarized by:

$$\Pi_n\left(h, h'\right) = \begin{array}{c|cccc} & S & I & R & D \\ \hline S & 1-e_n & e_n & 0 & 0 \\ I & 0 & 1-\pi^R-\pi^D & \pi^R & \pi^D \\ R & 0 & 0 & 1 & 0 \\ D & 0 & 0 & 0 & 1 \end{array}$$

Firms, wages and the labor market. The labor market is characterized by random search. The output from a match is given by $y = \alpha^h z$. We assume $\alpha^I < \alpha^S = \alpha^R$, i.e. infection reduces health-specific productivity but recovery fully restores it. Match-specific productivity takes on a discrete set of values, $z \in \{z_0, \ldots, z_{N_z}\}$. The productivity of a new match starts at the lowest value z_0 and increases to the next level with probability ξ as long as the match is actively producing.

Once matched with a worker, firms face three choices every period: i) keep the match active and produce, ii) pause production and become idle, or iii) permanently terminate the match. Active firms produce, pay workers their wage w (discussed below) and incur a fixed operating cost c_F. Firms that pause production avoid this fixed cost but still fulfill their payroll obligations.[1] Production is paused when output falls to a level that is unable to offset operating costs, possibly due

[1] The decision of pausing or resuming production is frictionless. Further, workers in idle matches remain on payroll and do not look for jobs.

to worker infection or government-imposed lockdown.[2] Once a match is permanently terminated, there is no option to recall the worker. Therefore, a firm exercises this option only when the surplus that it captures from the match is negative.

There are two types of firms in the nonessential sector. An ω share of firms are financially constrained (C), and they cannot run a per-period loss larger than a productivity-specific limit $\underline{a}(z)$.[3] This dependence on productivity allows us to capture any systemic variation in the amount of borrowing that firms can tap into. When the financial constraint binds, the firm is forced to put its worker on temporary layoff. The recall option arrives at exogenous rate r, but recalls occur only if both parties agree to resume the match. This recall option may disappear permanently with exogenous probability χ_r each period or when the worker finds another job while on layoff. Other firms are unconstrained (U), and their per-period profits are not subject to any requirement.

In addition to endogenous separations initiated by the firm or the worker, matches also separate exogenously at rate δ. This type of separation also leads to a temporary layoff with a recall option.

In summary, temporary layoffs occur because of i) binding financial constraints or ii) exogenous separations. Meanwhile, permanent separations occur when i) the firm or worker's match surplus is negative, ii) a worker on temporary layoff finds a new job, or iii) the recall option expires.

Wages are paid as a health-dependent piece rate $\phi\alpha^h$ of match productivity z.[4] The piece rate implies that wages rise with productivity. Wages are downward rigid: Getting infected reduces productivity but does not result in lower pay. The possibility of job dissolution and loss of match capital implies that infection can result in long-term earnings losses for the households.

Taking stock, the model allows for inefficient separations through several margins. First, financial frictions potentially lead to separations of highly productive matches. While these have a recall option, that option may expire or the worker may start a new job. Second, some exogenous separations eventually lead to permanent separations and are potentially inefficient. Lastly, sticky wages, in conjunction with financial frictions, cause otherwise perfectly viable matches to separate.

To match with workers, entrants pay a cost κ to post a vacancy. Meetings with a worker happen with probability $q(\theta)$, where labor market tightness $\theta = v/u$ is the ratio of the mass of vacancies and unemployed workers. The analogous probability for workers is $f(\theta) = \theta q(\theta)$. Labor markets are segmented, i.e. workers in a given sector can only meet with firms in the same sector.

Government. The government has several policy tools. It can reduce economic interactions through a containment policy in the form of a proportional tax $\tau_q \in [0, 1]$ on match output in the nonessential sector. It can pay unemployment benefits b to households and provide payroll subsidies to nonessential firms by covering a fraction $\tau_p \in [0, 1]$ of wages.

[2] Understanding the policy tools to keep firms in business during the ongoing COVID-19 pandemic is an important part of the policy debate. At the same time, because of the link between economic activity and the spread of the virus, saving firms need not come at the cost of more contagion. We model a fixed cost and the decision to "pause" production precisely to allow for this. If the fixed cost is sufficiently high, firms may be better off remaining idle even if the government covers a large share of the wage bill.

[3] This friction captures the idea that not all firms can access financial markets under the same terms, and they may furlough their worker, even if the net present value of the match to the firm is still positive.

[4] The dependence on health captures the fact that the outside option of a worker depends on her health.

Key differences of the essential sector. Essential firms differ from nonessential firms in three ways. First, essential firms do not have the option to pause production. Second, all essential firms are financially unconstrained. Third, payroll and containment policies do not apply to essential firms, while changes in UI generosity affect both sectors through workers' outside option.

Timing. Each period opens during the production and consumption stage: Matched firms decide whether to operate or pause production; active worker-firm pairs produce; wages are paid to workers; and UI benefits are paid to the unemployed. Next, health shocks are realized. Then the labor market opens: Recall options stochastically expire; firms create vacancies; new matches are formed; temporarily laid off workers may be recalled; and exogenous job separations occur. Next, match productivity in active matches stochastically improve. Finally, matched workers and firms unilaterally decide whether to keep or terminate the match before entering the next period.

2.2 Household Problem

$W_k^h(z,w)$ denotes the value of an employed household with health $h \in \{S, I, R\}$, matched to a firm of type $k \in \{C, U\}$, with productivity z and wage w.[5] Similarly, $U_{T,k}^h(z,w)$ and U_P^h are the values of unemployed households on temporary and permanent layoff (i.e. with and without a recall option), respectively. Finally, $J_k^h(z,w)$ is the value of a firm matched with a worker, $V_{T,k}^h(z,w)$ is the value of a vacant firm with a worker on temporary layoff, and V is the value of a new entrant.

In each period, the worker and the firm have the option to dissolve an existing match permanently. Let $d_{W,k}^h, d_{J,k}^h \in \{0,1\}$ indicate that an *existing* match yields positive surplus to the worker and firm, respectively. The joint outcome is then given by $d_k^h(z,w) = d_{W,k}^h(z,w) \times d_{J,k}^h(z,w)$. These indicators solve the following problems:

$$d_{W,k}^h(z,w) = \arg\max_{d\in\{0,1\}} \left\{ d \times W_k^h(z,w) + (1-d) \times U_P^h \right\}$$
$$d_{J,k}^h(z,w) = \arg\max_{d\in\{0,1\}} \left\{ d \times J_k^h(z,w) + (1-d) \times V \right\}$$

Upon contact, firms and unemployed workers decide whether to initiate an employment relationship. Let $d_{U_T,k,k'}^h \in \{0,1\}$ indicate whether a *new* match with a firm of type k' yields positive surplus to a worker on temporary layoff from a firm of type k, with productivity z and wage w:[6]

$$d_{U_T,k,k'}^h(z,w) = \arg\max_{d\in\{0,1\}} \left\{ d \times W_{k'}^h\left(z_0, w^h\right) + (1-d) \times U_{T,k}^h(z,w) \right\}$$

If the worker declines the offer, she remains unemployed and keeps the recall option from the previous match $U_{T,k}^h(z,w)$. Otherwise, she starts at the lowest productivity and the wage associated with it. A contact results in a new job if both parties agree: $d_{k,k'}^h(z,w) = d_{U_T,k,k'}^h(z,w) \times d_{J,k}^h(z_0,w^h)$.

[5] w is a state variable because wage rigidity implies that health status does not pin down wages. For example, an infected worker that started her job prior to being infected would be paid the wage of a non-infected worker.

[6] Note that state variables (z,w) in this indicator function refer to the *outside* option when the new firm is financially unconstrained, i.e. the productivity and wage in the latest job to which the worker might be recalled.

The value of an employed household working for a firm of type $k \in \{C, U\}$ is given by:

$$
\begin{aligned}
W_k^h(z,w) = u(w) + \beta \sum_{h' \in \{S,I,R\}} \Pi_l(h,h') \Big[\delta \, \mathbb{E}_{z'|z,l} \, U_{T,k}^{h'} \Big(z', \max\Big\{w, w^{h'}\Big\}\Big) \\
+ (1-\delta)\, \mathbb{E}_{z'|z,l} \, \widetilde{W}_k^{h'} \Big(z', \max\Big\{w, w^{h'}\Big\}\Big)\Big],
\end{aligned} \tag{2}
$$

where l refers to the firm's production decision (active or idle).[7] The max operator captures downward wage rigidity, which only binds when a susceptible worker becomes infected on the job or during temporary layoff. Note that wages rise as match capital z improves but we suppress this dependence for conciseness. The match exogenously dissolves with probability δ, leading to a temporary layoff. If the match survives with the complementary probability, the worker moves to the endogenous decision stage and obtains continuation value $\widetilde{W}_k^{h'}$ given by:

$$
\widetilde{W}_k^h(z,w) = \Big(1 - \gamma_k^h(z,w)\Big) \Big[d_k^h(z,w)\, W_k^h(z,w) + \Big(1 - d_k^h(z,w)\Big) U_P^h \Big] + \gamma_k^h(z,w)\, U_{T,k}^h(z,w).
$$

Indicator $\gamma_k^h \in \{0,1\}$ denotes whether the financial constraint binds. If it does, the worker goes on temporary layoff. The financial constraint is a requirement on per-period profits given by:

$$
\gamma_C^h(z,w) = \mathbb{I}\Big\{(1-\tau_q)\,\alpha^h z - (1-\tau_p)\, w - c_F \leq -\underline{a}(z)\Big\} \quad \text{and} \quad \gamma_U^h(z,w) = 0,
$$

where τ_q is the containment policy modeled as a tax on output and τ_p controls the payroll subsidy provided to firms. Next, the value of a worker on temporary layoff is given by:

$$
\begin{aligned}
U_{T,k}^h(z,w) = u(b) + \beta \sum_{h' \in \{S,I,R\}} \Pi_0(h,h')(1-\chi_r) \Big[f(\theta)\, \mathbb{E}_{k'} \widetilde{W}_{k,k'}^{h'}(z,w) \\
+ r\, \widetilde{W}_k^{h'} \Big(z, \max\Big\{w, w^{h'}\Big\}\Big) + (1 - f(\theta) - r)\, U_{T,k}^{h'} \Big(z, \max\Big\{w, w^{h'}\Big\}\Big)\Big] \\
+ \sum_{h' \in \{S,I,R\}} \Pi_0(h,h')\, \chi_r \Big[f(\theta)\, \mathbb{E}_{k'} \widetilde{W}_{k'}^{h'}(z_0, w^{h'}) + (1 - f(\theta))\, U_P^{h'} \Big].
\end{aligned} \tag{3}
$$

The recall option survives with probability $(1-\chi_r)$, in which case the worker gets recalled with probability r and the match maintains the pre-layoff productivity z. The worker can receive a new offer with probability $f(\theta)$ from a firm of type k'. The value of having this offer is given by:[8]

$$
\begin{aligned}
\widetilde{W}_{k,k'}^h(z,w) = \Big(1 - \gamma_{k'}^h\Big(z_0, w^h\Big)\Big) \Big[d_{k,k'}^h(z,w)\, W_{k'}^h\Big(z_0, w^h\Big) + \Big(1 - d_{k,k'}^h(z,w)\Big) U_{T,k}^h(z,w) \Big] \\
+ \gamma_{k'}^h\Big(z_0, w^h\Big)\, U_{T,k}^h\Big(z_0, w^h\Big).
\end{aligned} \tag{4}
$$

[7] The expectation over match productivity z, $\mathbb{E}_{z'|z,l}$, also depends on the firm's production decision l because if the match pauses operating, productivity remains constant.

[8] If the firm is financially unconstrained but the match is not formed, the worker keeps her recall option from the previous match. Hence, at the end of the first line of Equation (4), we have $U_{T,k}^h(z,w)$. We assume that when the financial constraint of the new firm binds, the worker continues with a recall option from the new match. Therefore, in the second line of Equation (4), we have $U_{T,k}^h\left(z_0, w^h\right)$.

The expectation operators in Equation (3) account for the fact that the new firm a worker meets may be financially constrained:

$$
\begin{aligned}
\mathbb{E}_{k'}\,\widetilde{W}_{k'}^{h'}\left(z_0, w^{h'}\right) &= \omega\,\widetilde{W}_{C}^{h'}\left(z_0, w^{h'}\right) + (1-\omega)\,\widetilde{W}_{U}^{h'}\left(z_0, w^{h'}\right) \\
\mathbb{E}_{k'}\,\widetilde{W}_{k,k'}^{h'}(z,w) &= \omega\,\widetilde{W}_{k,C}^{h'}(z,w) + (1-\omega)\,\widetilde{W}_{k,U}^{h'}(z,w)\,.
\end{aligned} \tag{5}
$$

Finally, the value of an unemployed household with no recall option is:

$$
U_P^h = u(b) + \beta \sum_{h' \in \{S,I,R\}} \Pi_0\left(h,h'\right)\left[f(\theta)\,\mathbb{E}_{k'}\,\widetilde{W}_{k'}^{h'}\left(z_0, w^{h'}\right) + (1-f(\theta))\,U_P^{h'}\right]. \tag{6}
$$

2.3 Firm Problem

The value of a firm of type k, productivity z, matched with a worker of health h is given by:

$$
\begin{aligned}
J_k^h(z,w) = \max_{l\in\{0,1\}} & \left\{ l \times \left[(1-\tau_q)\,\alpha^h z - (1-\tau_p)\,w - c_F\right] + (1-l)\times\left[-(1-\tau_p)\,w\right]\right\} \\
&+ \beta \sum_{h'\in\{S,I,R\}} \Pi_l\left(h,h'\right)\left[\delta\,\mathbb{E}_{z'|z,l}\,V_{T,k}^{h'}\left(z', \max\left\{w, w^{h'}\right\}\right)\right. \\
&\left. + (1-\delta)\,\mathbb{E}_{z'|z,l}\,\widetilde{J}_k^{h'}\left(z', \max\left\{w, w^{h'}\right\}\right)\right].
\end{aligned} \tag{7}
$$

The first max operator reflects the firm's production decision. If production is paused ($l^h(z,w)=0$), the worker faces a lower risk of infection, remains attached to the firm, but match productivity remains constant. If the firm decides to produce, it pays the operating cost c_F in addition to wages. Here, the worker is subject to additional infection risk from active employment but match quality stochastically improves. The value of a matched firm at the separation decision stage is:

$$
\widetilde{J}_k^h(z,w) = \left(1-\gamma_k^h(z,w)\right)\left[d_k^h(z,w)\,J_k^h(z,w) + \left(1-d_k^h(z,w)\right)V\right] + \gamma_k^h(z,w)\,V_{T,k}^h(z,w)\,.
$$

The value of a vacant firm with a furloughed employee is given by:

$$
\begin{aligned}
V_{T,k}^h(z,w) = \beta(1-\chi_r) & \sum_{h'\in\{S,I,R\}} \Pi_0\left(h,h'\right)\times\left[f(\theta)\left[\mathbb{E}_{k'}\,(1-\gamma_{k'}^{h'}(z_0,w^{h'}))\right.\right. \\
&\left.\left[d_{k,k'}^{h'}(z,w)\,V + (1-d_{k,k'}^{h'}(z,w))\,V_{T,k}^{h'}\left(z, \max\left\{w, w^{h'}\right\}\right)\right] + \gamma_{k'}^{h'}(z_0,w^{h'})V\right] \\
&\left. + r\,\widetilde{J}_k^{h'}\left(z, \max\left\{w, w^{h'}\right\}\right) + (1-f(\theta)-r)\,V_{T,k}^{h'}\left(z, \max\left\{w, w^{h'}\right\}\right)\right] + \beta\chi_r V.
\end{aligned} \tag{8}
$$

The first term in the second line (brackets) indicates that when a worker on temporary layoff rejects a new offer, she keeps her recall option to her previous employer, but if she accepts the new offer, the firm is left vacant.[9] The last term in the second line captures the case when the new firm's

[9] Here, $\mathbb{E}_{k'}$ is the expectation on whether the firm's financial constraint binds and resembles Equation (5).

financial constraint binds; the worker continues with a recall option from the new match.

Value of posting a new vacancy is given by:

$$
\begin{aligned}
V = -\kappa + \beta q(\theta) \frac{1}{u} \sum_{h,h' \in \{S,I,R\}} \Pi_0(h,h') \Bigg[& \Big(u_P^h + \chi_r \sum_{k,z} u_{T,k}^h(z) \Big) \mathbb{E}_{k'} \widetilde{J}_{k'}^{h'} \left(z_0, w^{h'}\right) \\
+ (1-\chi_r) \sum_{k,z} u_{T,k}^h(z) \, \mathbb{E}_{k'} (1 - \gamma_{k'}^{h'}(z_0, w^{h'})) & \Big[d_{k,k'}^{h'}(z,w) J_{k'}^{h'}(z_0, w^{h'}) \\
+ \Big(1 - d_{k,k'}^{h'}(z,w)\Big) V \Big] & + \gamma_{k'}^{h'}(z_0, w^{h'}) V_{T,k'}^{h'}(z_0, w^{h'}) \Bigg].
\end{aligned} \tag{9}
$$

Here, $u_{T,k}^h(z)$ and u_P^h denote the mass of unemployed workers on temporary layoff with a recall option back to a job with match capital z and unemployed workers on permanent layoff, respectively, and $u = \sum_h \left(u_P^h + \sum_{k,z} u_{T,k}^h(z) \right)$ is the total mass of unemployed. When this firm meets with a worker, its financial type is revealed. If the firm-worker pair decides to keep the match, it becomes productive in the next period. We assume free entry: an infinite supply of potential new entrants pushes the value of posting a new vacancy to zero, $V = 0$.

Appendix A.1 defines a stationary equilibrium and A.2 provides computational details.

3 Calibration

We match several targets of the U.S. economy prior to and during the pandemic. In the pre-pandemic steady state, all individuals are susceptible, financial constraints are non binding, and the only government policy is the existing UI program. Table 1 summarizes calibrated parameters.

Externally calibrated parameters. The model period is a week. The utility function is given by $u(c) = \overline{u} + \frac{c^{1-\sigma}}{1-\sigma}$ as in Hall and Jones (2007), so that agents value life. We set $\sigma = 2$ and discuss the calibration strategy for $\overline{u}$ below.

We assume a CES matching function, implying that the job finding rate is $f(\theta) = \theta(1+\theta^\eta)^{-1/\eta}$. We set the matching function elasticity η to 0.4 (Hagedorn and Manovskii, 2008). We follow Gascon (2020), who measures the employment share of essential occupations and those that can be done remotely, and assign the essential sector an employment share of 54 percent. Furthermore, we assume that 80 percent of the firms in the nonessential sector become financially constrained at the onset of the epidemic ($\omega = 0.8$). Fujita and Moscarini (2017) show that the probability of exiting from unemployment through a recall approaches zero after six months of unemployment. This requires setting the stochastic expiration rate of the recall option χ_r to 1/26. We set the worker's share in output to $\phi = 2/3$. Finally, we target a pre-COVID monthly separation rate of 1.65 percent computed using the Current Population Survey (CPS) and set δ to 0.0042.

To discipline the model's SIR component, we follow Eichenbaum, Rebelo, and Trabandt (2020). Assuming a mortality rate of 0.5 percent and that infected individuals either recover or die from infection within 18 days on average ($\pi^D + \pi^R = 7/18$), we obtain $\pi^D = 0.005 \times 7/18$ and $\pi^R = (1 - 0.005) \times 7/18$. Finally, we normalize the productivity of susceptible and recovered workers, α^S and α^R, to one, and assume a 20 percent loss in productivity when infected ($\alpha^I = 0.8$).

Table 1: Calibrated parameters

Externally calibrated			
Parameter	Description	Value	Source
β	Discount factor	0.999	5% annual interest rate
σ	Utility curvature	2	Set
η	Matching function parameter	0.4	Hagedorn and Manovskii (2020)
ω	Firm share with financial constraint	0.8	Set
χ_r	Recall expiration rate	1/26	Fujita and Moscarini (2017)
ϕ	Worker output share	2/3	Set
δ	Separation rate	0.0042	Weekly job separation rate
π^D	Death probability	$0.005 \times \frac{7}{18}$	Eichenbaum, Rebelo, and Trabandt (2020)
π^R	Recovery probability	$(1-0.005) \times \frac{7}{18}$	Eichenbaum, Rebelo, and Trabandt (2020)
α^S	Susceptible productivity	1	Normalization
α^R	Recovered productivity	1	Normalization
α^I	Infected productivity	0.8	Eichenbaum, Rebelo, and Trabandt (2020)

Internally calibrated					
Parameter	Description	Value	Target	Data	Model
			Steady state		
ξ	Productivity upgrade probability	0.007	p90/p10 earnings	6.30	5.73
b	UI benefit level	0.911	Average replacement rate	0.40	0.40
r	Recall probability	0.037	Recall share in UE transitions	0.40	0.37
κ	Vacancy posting cost	0.102	Unemployment rate	0.037	0.042
c_F	Operating cost	0.579	Profit to cost ratio	0.25	0.20
π_1	Infection due to work	0.317	Infection share due to work	0.33	0.33
π_2	Infection due to other reasons	0.587	Dead and recovered share	0.60	0.60
$\overline{u}$	Fixed utility	0.757	Statistical value of life	10M $	10M $
			Transition		
$\underline{a}_0$	Constraint intercept	0.80	Unemployment during containment	0.20	0.22
$\underline{a}_1$	Constraint slope	0.50	Unemployment incidence below median earnings	0.72	0.76
τ_q	Containment measure	0.75	Firm share with closures during containment	0.30	0.28

Notes: This table provides a list of externally and internally calibrated parameters. Please refer to the main text for a detailed discussion.

Internally calibrated parameters. We calibrate eight of the remaining 11 parameters to match steady-state moments of the U.S. economy prior to the pandemic, and the remaining three by simulating the COVID-19 pandemic and matching moments along the transition.

We first discuss the steady-state moments. The probability ξ of a productivity upgrade of an actively producing match has a pronounced effect on the earnings dispersion. Therefore, we target the 90th to 10th percentile ratio of the labor earnings distribution among employed workers, which is 6.30 in the Survey of Program and Income Participation (SIPP).

We target a replacement rate of 40 percent to discipline the UI payments b. The recall probability r is chosen to match a 40 percent share of recalls in UE flows (Fujita and Moscarini, 2017).

Firms face two costs. We choose the vacancy posting cost κ to match an unemployment rate of 3.7 percent. Using aggregate income statements from the Internal Revenue Service (IRS), we find that the ratio of profits to business expenses is around 25 percent for sole proprietorships in 2017. We calibrate the fixed operating cost incurred by active firms c_F to match this ratio.

We now describe the calibration of parameters related to the epidemic. We choose π_1 such that the infections resulting from labor market activity account for one third of all infections. To pin down π_2, we target a 60 percent combined share of recovered and dead individuals in a simple SIR model with no behavioral response from households.[10] Finally, because $\overline{u}$ governs how much individuals value life over death, we choose $\overline{u}$ to match a statistical value of life of \$10 million as in Glover et al. (2020). Appendix A.3 provides more details.

Finally, we calibrate the remaining three parameters by simulating the COVID-19 pandemic and matching moments along the transition. Specifically, we populate the economy with an initial mass of 0.001 infected individuals.[11] We assume that financial constraints in the nonessential sector become operational, and that the only government response is to implement a containment measure τ_q in the nonessential sector during the first quarter of the pandemic.

The financial constraint is important for our substantive results, so we discuss its calibration in more detail. The constraint depends linearly on productivity: $\underline{a}(z) = \underline{a}_0 + \underline{a}_1 z$. The constant $\underline{a}_0$ has a pronounced effect on the level of unemployment during the epidemic. We choose this to match a maximum unemployment rate of 20 percent during the first quarter of the epidemic.[12] The slope of the constraint, $\underline{a}_1$, determines which matches are predisposed to separation during the epidemic. If $\underline{a}_1 = 0$, wage rigidity implies that high-wage matches get destroyed. In contrast, a positive $\underline{a}_1$ makes low-wage matches more likely to dissolve. Since $\underline{a}_1$ determines the wage composition of job losses, we choose it to match the incidence of the rise in unemployment across the earnings distribution. Using the CPS, we divide occupations into employment-weighted earnings quantiles, and for each

[10] To do so, we simulate the system of equations given in Equation (A1) in Appendix A.1 under $\pi_1 = 0$ and calculate the total number of recovered and dead individuals in the steady state as a share of initial population.

[11] We apportion this total initial infected mass to different labor market states based on the population shares of workers in steady state.

[12] During the early stages of the shutdown in the U.S., there were many estimates of the peak unemployment rate in the absence of a policy response. Şahin, Tasci, and Yan (2020) estimated 16 percent; Treasury Secretary Steven Mnuchin stated a peak of 25 percent; and Faria-e Castro (2020a) estimated 32.1 percent. We take 20 percent as our target and show the results when unemployment peaks at 35 percent under stricter containment measures.

quantile, calculate the change in temporary unemployment from January 2020 to April 2020. We find that occupations below the median of the earnings distribution accounted for 72 percent of the total increase in temporary unemployment.[13] We target this moment to discipline $\underline{a}_1$.

Finally, we choose the strictness of the containment policy τ_q to match the fraction of businesses with temporary closings during the pandemic. According to the Small Business Pulse Survey of the U.S. Census Bureau, the fraction of businesses with at least one day of temporary closing in a week in May 2020 was around 30 percent. We map temporary closings to firms pausing production in the model and calculate the fraction of idle matches in the nonessential sector.

4 Results

We now analyze the effects of an epidemic under various labor market policies, starting with a baseline containment of $\tau_q = 0.75$ and no accompanying fiscal support, which we compare to two extreme cost-equivalent options: channel all additional transfers through UI or through payroll subsidies. We then solve for the optimal mix of these policies and consider how this optimal mix changes with the strictness of containment. In all our experiments, we assume that policies are introduced coincident with the inception of the epidemic, and last for one quarter (13 weeks).[14]

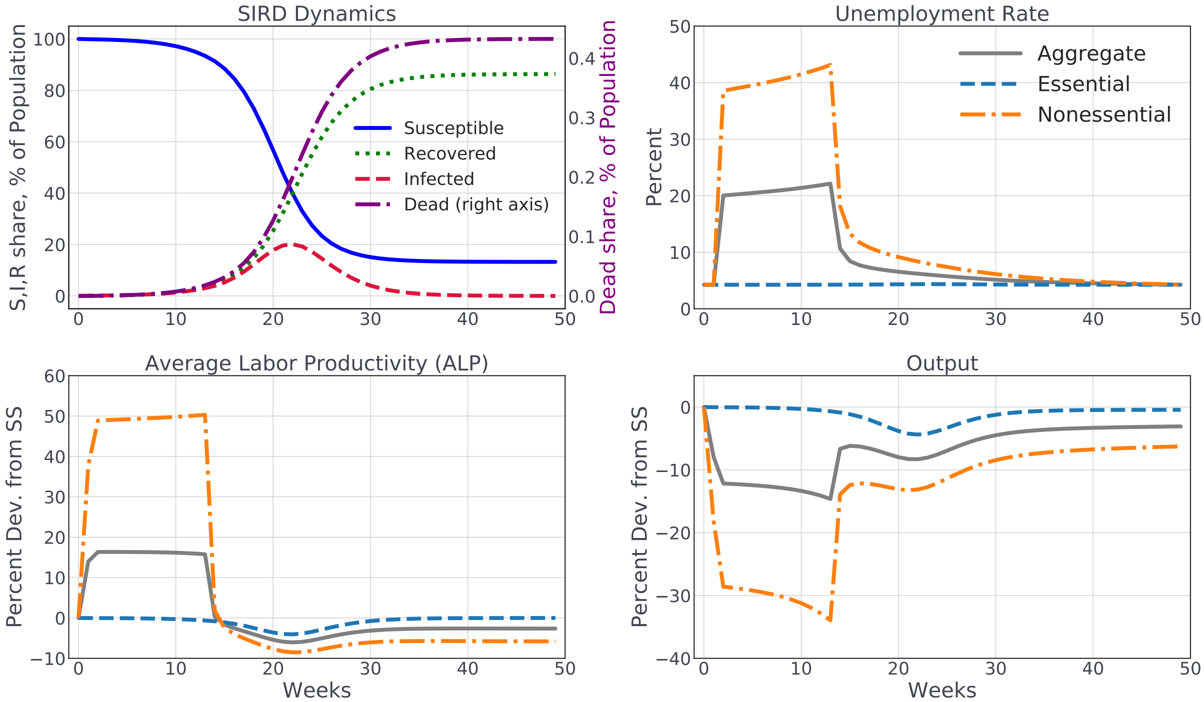
No fiscal response. Figure 1 shows the results. Within a year, around 80 percent of the population is infected and eventually recovers, resulting in the death of 0.43 percent of the initial population.[15] The nonessential sector unemployment rate rises to around 40 percent, resulting in a peak aggregate unemployment rate of 22 percent. In the data, around three-fourths of the total increase in unemployment is attributable to occupations below the median of the earnings distribution (Section 3). Since our model is calibrated to match this feature, nonessential sector layoffs are concentrated among these lower-quality matches, which face stricter financial constraints and smaller surpluses. This leads to a short-lived rise in average labor productivity (ALP) during the containment. Permanently dissolved matches result in the loss of match capital built over time. As new but lowest-productivity (z_0) matches are formed post-containment, nonessential ALP falls to nine percent below steady state and remains persistently low. In the essential sector, which is not subject to containment, a limited drop in ALP is driven mostly by infections reducing worker productivity. As such, this provides a benchmark on the effects of infection-related productivity losses. Meanwhile, aggregate output declines by 14 percent during containment. Despite the full employment recovery within one year, aggregate output remains three percent lower than its pre-crisis level due to the loss of match capital built over long-term employment relationships.

[13] Amburgey and Birinci (2020) find job losses to be more prevalent for low income workers within both the sample of temporary layoffs and all unemployed workers.

[14] We have also considered longer containment measures. A containment policy that lasts two quarters has a larger impact on match surplus, thereby making higher productivity matches more likely to terminate relative to a shorter containment. This raises the value of granting payroll subsidies that can save these jobs.

[15] Our model predicts a high infection rate relative to the data, because our exercise only limits contagion through reduced economic activity but does not account for other behavioral responses such as social distancing, increased hygiene, and the use of protective equipment that may reduce infections, which could be captured by a lower π_2. Furthermore, reported data on infections are beset by undercounting due to hidden cases, testing constraints, and asymptomatic individuals.

Figure 1: No Fiscal Response



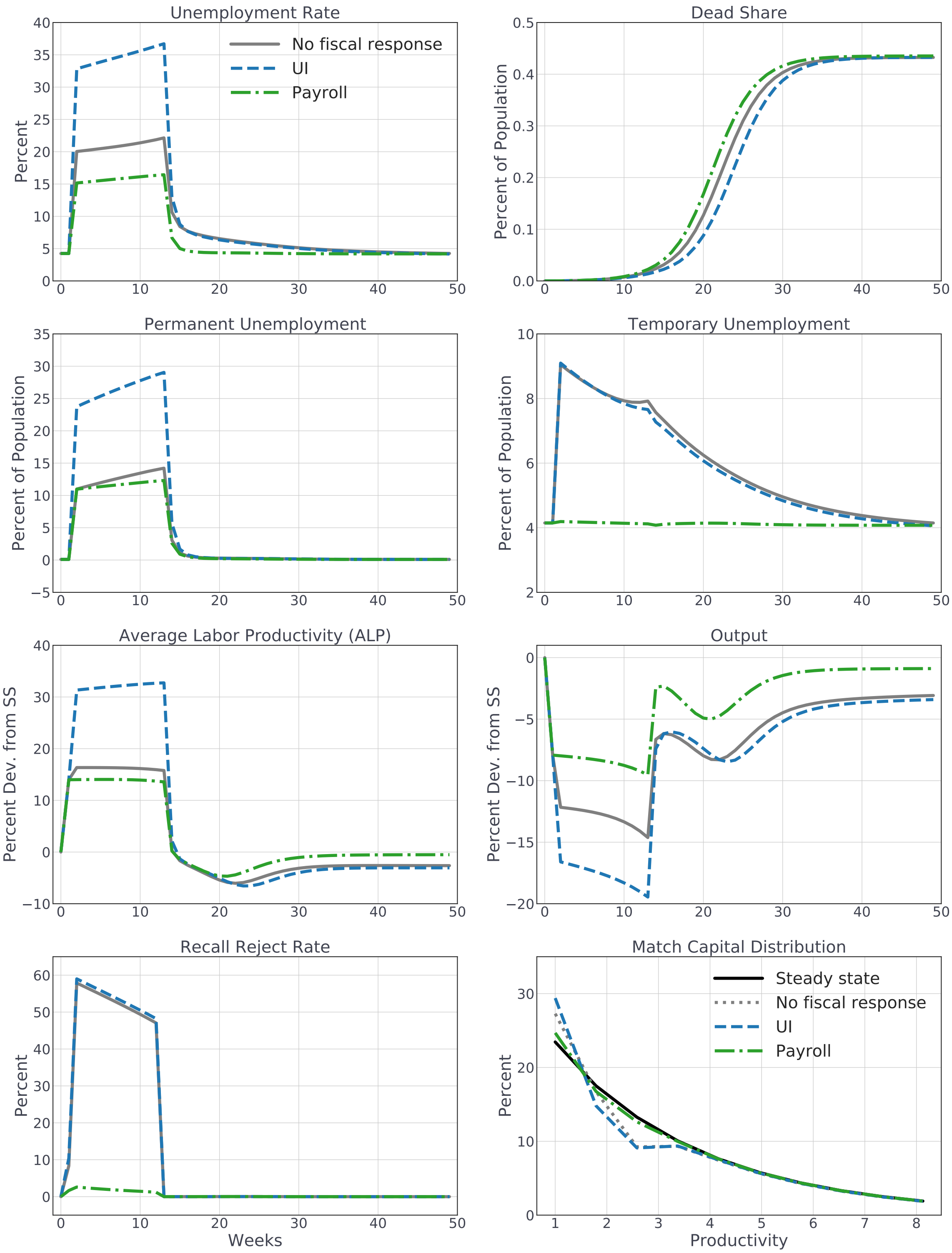
Notes: This figure plots the effects of the epidemic on health and labor market dynamics when the government implements a containment for one quarter without any accompanying fiscal response.

UI vs. payroll subsidies. We now study the expansion of the UI program and payroll subsidies one at a time. The UI benefit expansion is motivated by the CARES Act, which provides an additional \$600 in weekly unemployment benefits on top of regular payments that average \$400. To make cost-equivalent comparisons, we consider an alternative where the cost incurred by this UI expansion is instead diverted toward payroll subsidies, implying $\tau_p = 0.47$.[16] Figure 2 plots the infection dynamics and labor market outcomes under these two cases. Relative to the no-fiscal-response scenario, UI expansion results in a larger increase in unemployment driven by additional permanent dissolutions since a high value of unemployment yields a negative surplus for low-value matches. In contrast, payroll subsidies dampen the rise in unemployment by preventing temporary layoffs otherwise undertaken by financially-constrained firms. The larger reduction in economic activity under the UI expansion leads to a slower rise in infections, leading to both a delay and a decline in the number of deaths.[17] Under the UI expansion, ALP rises temporarily due to the

[16] In the baseline calibration, $b = 0.911$ corresponds to an average \$400 weekly benefit amount and 40 percent replacement rate. Under the CARES Act, the total weekly benefit amount in the model then becomes $2.5 \times b$. The present discounted value of providing the additional benefit amount of $1.5 \times b$ over a quarter is cost-equivalent to the 47 percent payroll subsidy provided to the firms in the nonessential sector over a quarter.

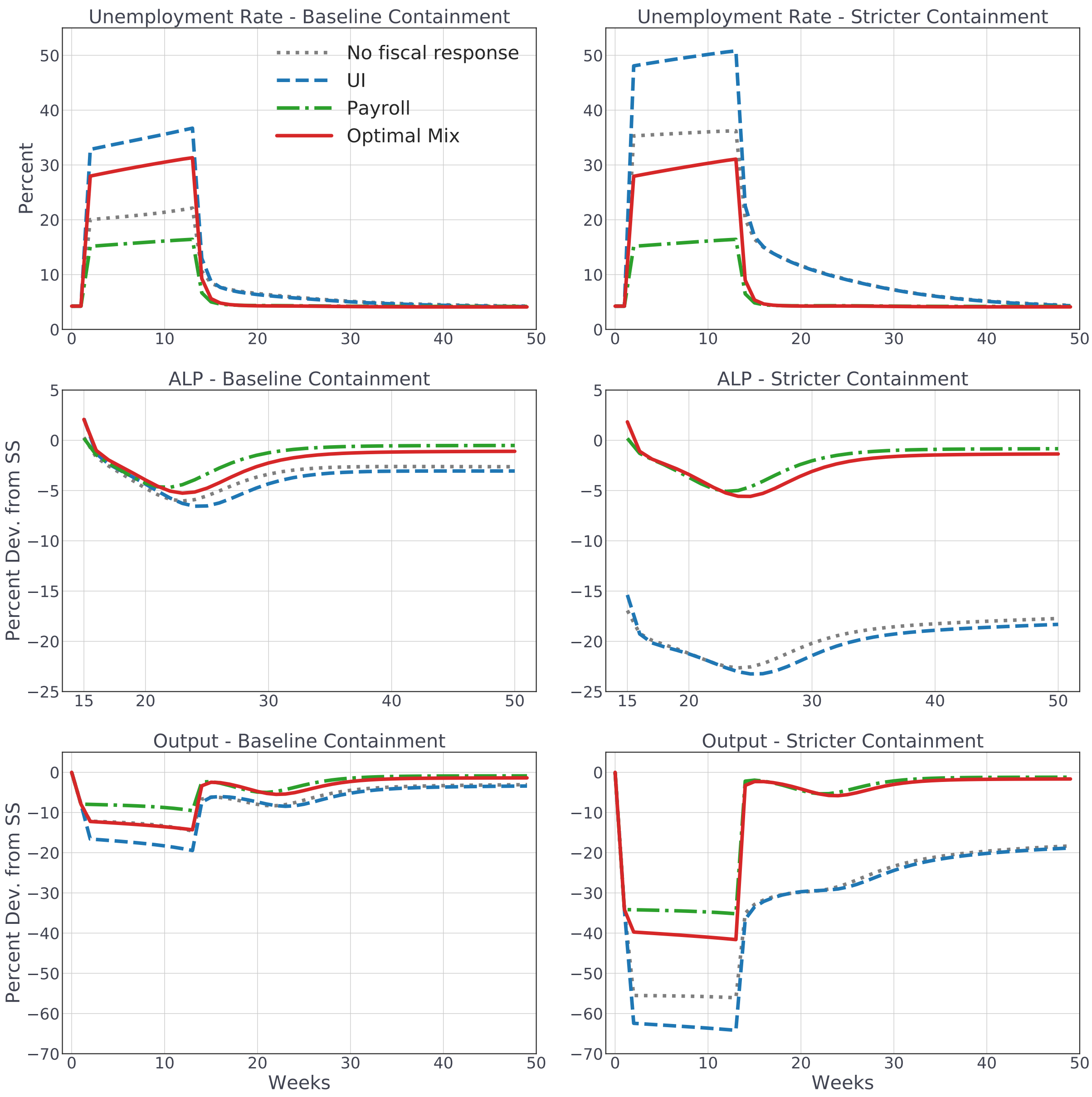
[17] The payroll subsidy program results in roughly 15,000 more deaths after one year. Since we do not model how delaying infections under the UI expansion may result in improved preparedness of the health system, we view this difference in death toll as a lower bound. However, in the absence of an option to pause production, the death gap between UI and payroll would be higher, given that some firms that receive payroll subsidies choose to pause production in the current model.

Figure 2: UI Expansion vs. Payroll Subsidies



Notes: This figure plots the effects of the epidemic on health and labor market dynamics when the government implements a containment i) without any accompanying fiscal response, ii) with only an expansion of UI policy for one quarter, or iii) with only an introduction of payroll subsidies for one quarter. The present discounted value of government spending under only a UI expansion and only a payroll subsidy are equal. In all figures except the last one, the horizontal axis denotes weeks.

Figure 3: Optimal Policy Mix under Baseline and Stricter Containment Measures



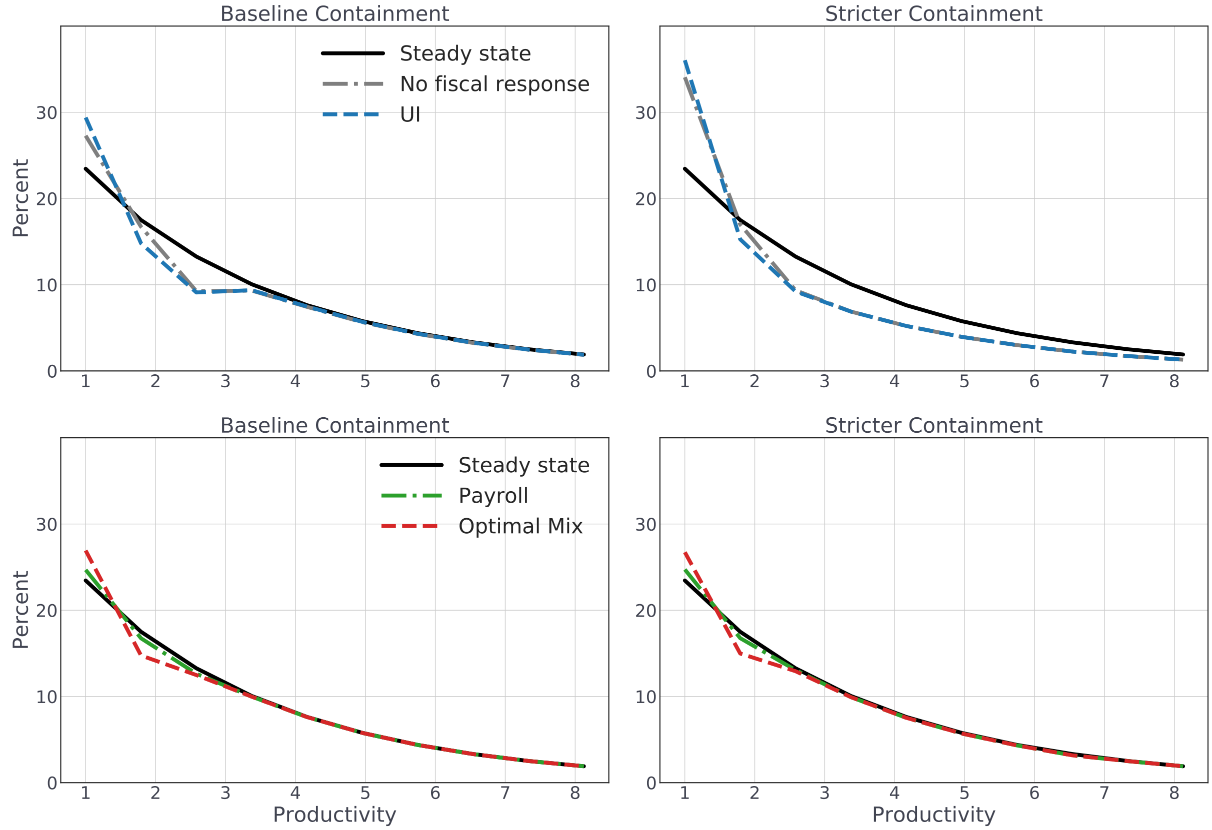
Notes: This figure plots the effects of the epidemic on labor market dynamics when the government implements a containment i) without any accompanying fiscal response, ii) with only an expansion of UI policy for one quarter, iii) with only an introduction of payroll subsidies for one quarter, and iv) with the optimal policy mix for one quarter. The present discounted value of government spending across these three alternatives are equal. In the second row of panels, we plot Average Labor Productivity (ALP) after the containment period ends.

destruction of low-productivity matches but experiences a more severe and persistent fall to seven percent below pre-crisis levels. ALP dynamics post-containment mirror a similarly persistent drop in output. Payroll subsidies, on the other hand, allow firms to retain matches without resorting to temporary layoffs that may eventually dissolve, if recalls do not materialize. Conditional on being temporarily laid off, payroll subsidies also increase the incidence of recalls, given that firms engaged in rehiring are less likely to face financial constraints that may cause recall rejections. These result in a less-severe drop and faster recovery of both ALP and output. In order to understand ALP and output dynamics, the final panel of Figure 2 compares the match-capital distribution pre-containment (steady state) and post-containment under different policy responses. Under the no-fiscal-response scenario (gray line), relative to the steady state, the post-containment distribution shifts toward low-match capital jobs as accumulated capital is destroyed. This effect is exacerbated by the UI expansion (blue line), but payroll subsidies (green line) preserve match capital so much so that the post-containment employment distribution remains close to the pre-crisis steady state. The distributions demonstrate that the UI expansion and payroll subsidies have differential effects on the productivity ladder—the former causes workers to fall off the ladder but provides insurance to job losers, while the latter preserves workers' position along the ladder but is a less-potent direct insurance mechanism for job losers. In terms of welfare, relative to the no-fiscal-response scenario, the UI expansion results in a welfare gain equivalent to 0.18 percent of additional lifetime consumption, while payroll subsidies result in a welfare gain of 0.76 percent.[18] This implies that when considered in isolation, a payroll subsidy is preferred over a cost-equivalent UI expansion.

Optimal mix of policies. What is the optimal policy mix? Given a baseline containment rate of $\tau_q = 0.75$, we solve for b and τ_p to maximize welfare subject to preserving cost-equivalence with the preceding exercise. The optimal policy prescribes an 80 percent budget allocation toward UI while the remaining 20 percent is spent on payroll subsidies, yielding a welfare gain of 0.85 percent in additional lifetime consumption relative to a no-fiscal-response alternative. This implies $b^* = 2.2$ and $\tau_p^* = 0.1$. The left column of Figure 3 shows that under the optimal policy, the relatively generous UI payments induce a large increase in unemployment, more than halfway between the no-fiscal-response and the full-UI scenario. However, the 10 percent payroll subsidy goes a long way toward preserving match capital, as evidenced by the less-severe drop in ALP. An important implication is that even if the unemployment rate is drastically higher under the optimal policy (red) relative to having no fiscal response (gray), output during containment is the same and recovers much faster under the optimal policy. The faster recovery occurs because firm-worker pairs with high match capital resume production once the containment period ends. This is supported by the left column of Figure 4, where the match capital distribution significantly worsens under both no-fiscal-response (gray) and full UI (blue), but the optimal policy with *only* $\tau_p^* = 0.1$ (red) is capable of preserving match capital close to steady-state levels and, importantly, accomplishes what a large payroll subsidy of $\tau_p = 0.47$ (green) would have achieved. This brings us to two important conclusions. First, a payroll subsidy that is just enough to prevent high-productivity

[18] See Appendix A.4 for details of the welfare calculation.

Figure 4: Match Capital Distribution under Baseline and Stricter Containment Measures



Notes: This figure plots the pre-containment (steady state) and post-containment (7 weeks after the containment) match capital distribution. The post-containment distributions are shown separately for the following scenarios: i) having no fiscal response, ii) only expanding UI benefits, iii) only introducing payroll subsidies, and iv) implementing the optimal policy mix.

matches from dissolving, eliminates the need for generous subsidies in excess of what firms need to weather the containment period. Second, UI and payroll subsidies target workers on different rungs of the productivity ladder. On the one hand, payroll subsidies seek to preserve matches for highly productive workers and prevent their inflow into unemployment. On the other hand, for less-productive matches predisposed to dissolution even with payroll subsidies, UI serves as an insurance mechanism to smooth consumption. Thus, when considered in isolation, payroll subsidies prevail over UI expansions, but under an optimal policy mix, these two policies are complementary. A partial allocation of resources for payroll subsidies preserves match capital and also leaves a substantial budgetary space for additional UI payments for the inevitable increase in job loss.

Why does the optimal mix allocate a *smaller* share of funds to the payroll subsidy when it achieves a larger welfare gain relative to UI in isolation? The key to this result is the observation that the welfare gain from each dollar spent on payroll subsidies exhibits diminishing returns for two reasons. First, as more funds are allocated to subsidies (a higher τ_p), the marginal job preserved declines in productivity, and this additional spending has a negligible effect on stimulating a faster recovery. Second, since all firms benefit from the subsidies at the same rate, increasing τ_p further implies paying additional and unnecessary subsidies to high-productivity firms that do not face dissolution risk. To illustrate diminishing returns quantitatively, we calculate the welfare gain of a policy where the government spends 20 percent of the budget on payroll subsidies and does not change the generosity of UI benefits. The welfare gain of such a policy is 0.75 percent, very close to the welfare gain of spending the entire budget on payroll subsidies of 0.76 percent. Given these diminishing returns, the optimal policy prefers the permanent dissolution of low-productivity matches and uses the remaining funds to insure workers in those matches through UI.[19]

Finally, we ask how the optimal policy mix would change if the government had imposed a stricter lockdown ($\tau_q = 0.90$), which results in a peak unemployment rate of 35 percent. Holding the available budget fixed, we find that the optimal policy mix now prescribes a higher fraction, 40 percent, of the budget on payroll subsidies, implying less generous UI benefits $b^* = 1.9$ and twice the payroll subsidy $\tau_p^* = 0.2$.[20] This yields a welfare gain of 3.4 percent. The second column in Figure 3 shows that compared with the lax (baseline) containment, the no-fiscal-response scenario induces a much larger increase in the unemployment rate, as well as a significantly larger drop in ALP and, correspondingly, output. These effects are once again exacerbated by the UI-only policy, because strict containment turns even high-productivity matches to low surplus ones and makes them vulnerable to dissolution. The top right panel of Figure 4 shows that under no-fiscal-response (gray) and UI (blue), matches even at the top of the productivity distribution are lost. Firms that would have otherwise preserved their relationship with an experienced worker under a lax containment policy are no longer capable of doing so under strict containment. Thus, the optimal policy now prescribes a larger payroll subsidy ($\tau_p^* = 0.2$). The bottom right panel of Figure 4 shows that the match quality distribution under the optimal policy (red) gets close to the pre-crisis distribution, while a full-payroll subsidy (green) yields only marginal gains. As a result, the optimal policy significantly alleviates the drop in productivity and output even during containment, which is the reason why the welfare gain from the optimal mix becomes much higher under strict containment. Once again, we note that the 40 percent budget allocation on payroll subsidies captures most of the gains that a full budget allocation to payroll would have achieved.

Robustness and comparative statics. Do payroll subsidies always dominate UI expansion in isolation? Does the optimal mix always allocate more funds to UI expansion? We now study how our main results depend on several key parameters. This achieves two objectives. First, it allows us to better understand and illustrate the economic forces behind the main results. Second, while we conduct our analysis for the U.S., similar trade-offs should be present in other countries as well. During the pandemic, other labor markets could have differed in the importance of match-specific capital, the extent of financial frictions, or how pervasive recalls are. Our analysis can therefore speak to why different countries may find it optimal to implement a different mix of policies.

[19]Recall that the welfare gain from implementing the optimal mix is 0.85 percent, implying that 80 percent of the budget spent on UI expansion provides an additional 0.10 percentage point welfare gain.

[20]When we consider UI and payroll subsidy policies under stricter containment in isolation, we again find that payroll subsidies are preferred over the UI extension. Relative to no-fiscal policy, the welfare gain of the former is 3.33 percent and the welfare gain of the latter is 0.25 percent.

Table 2: Robustness and comparative statics

	Baseline	1.25r	1.5r	0.5ξ	2ξ	0.75$\underline{a}_1$	0.5$\underline{a}_1$	0.25$\underline{a}_1$
UI in isolation	0.18	0.18	0.17	0.17	0.13	0.17	0.16	0.15
Payroll subsidy in isolation	0.76	0.73	0.70	0.75	0.72	1.14	1.10	1.08
Optimal mix	0.85	0.81	0.79	0.84	0.80	1.23	1.16	1.12
Budget share of UI, %	80.0	83.1	83.0	83.2	47.1	74.7	53.7	34.4

Notes: This table summarizes welfare outcomes under different parametrizations of the model. "Baseline" refers to the calibration in Table 1. The other columns refer to parameterizations where recall probability r, productivity upgrade probability ξ, or the slope of the financial constraint $\underline{a}_1$ are varied. Welfare gains are reported in percent consumption equivalent units. The last row reports the share of total spending on UI in the optimal policy mix.

Specifically, we consider differences in recall probabilities (r), the speed of learning on the job (ξ), and how financial frictions vary across firms with different productivities ($\underline{a}_1$). For each exercise, we compute the welfare gain of introducing a UI expansion or a payroll subsidy in isolation, as well as the new optimal policy mix and its associated welfare gain. To facilitate comparability, we choose the policy parameters τ_p and b such that the policies are cost-equivalent with the baseline. In the case of financial frictions, we also recalibrate $\underline{a}_0$ to obtain the same peak unemployment as in our baseline. Results are summarized in Table 2.

A higher recall probability ensures that a lower share of temporary layoffs result in permanent match destruction and reduces the potential benefit of payroll subsidies. This effect is quantitatively small: A 25 or even 50 percent higher r reduces the budget share allocated to payroll subsidies in the optimal mix from 20 percent to 17 percent. There are three reasons for why a higher recall probability results in only a modest decline in the share of spending on payroll subsidies: i) containment measures induce negative surplus for some matches, leading to permanent separations that recalls cannot remedy, ii) productivity stagnates during temporary separation prior to recall, and iii) a higher recall probability reduces but does not completely eliminate the permanent expiration of the recall option and the severance of ties between the worker and the firm.

The rate at which productivity grows on the job (ξ) is an important determinant of optimal policy. We discipline this parameter by targeting the wage dispersion in the data. An alternative approach is to target the earnings losses upon job loss because ξ controls how much wages grow among job stayers relative to job losers. Reassuringly, our model does a good job in matching the initial earnings loss, while understating losses in the longer term by about 5 percentage points (see Appendix A.5). Regardless of the fit, our estimate for ξ may be biased upward, because inequality and the consequences of job loss in the data are shaped by a host of factors apart from differences in match productivity alone. To gauge the robustness of our conclusions, we solve for optimal policy by setting ξ to half and double that of the baseline value. Raising ξ by a factor of two makes long-tenure matches much more productive, thereby increasing the benefit of payroll subsidies. Consequently, optimal policy allocates 53 percent of the budget to this component. Conversely, lowering ξ dictates a lower share to be allocated to payroll subsidies given the reduced importance of match-specific capital. In isolation, payroll subsidies still provide a much larger welfare gain relative to a cost-equivalent UI expansion.

Another important aspect is the relationship between financial frictions and match productivity governed by $\underline{a}_1$. Whether constraints bind more for high- or low-productivity firms is important for the policy tradeoff. A lower $\underline{a}_1$ implies a tighter constraint for high-productivity matches. When these output-critical jobs are more predisposed to permanent dissolution, match preservation through payroll subsidies becomes more important. We find that reducing $\underline{a}_1$ down to a quarter of its baseline value increases the optimal spending on payroll subsidies to a level that is twice the proportion spent on UI. However, such a low value for $\underline{a}_1$ implies that separations from low-paying jobs (below the median wage) account for only 11 percent of the total increase in unemployment. This number is clearly at odds with the 72 percent share observed in the data, which is an integral part of how we discipline the distribution of job losses in the model.

5 Conclusion

The COVID-19 pandemic and the ensuing policy interventions to contain it have had unprecedented negative effects on the U.S. labor market. In response, the U.S. government implemented two types of labor market policies: expanding UI payments and granting payroll subsidies to vulnerable firms. In this paper, we study the usefulness of these policies both in isolation and in conjunction. The introduction of payroll subsidies alone is preferred over a cost-equivalent UI expansion as it preserves highly productive matches during containment, thus enabling a faster recovery of productivity and output following the lifting of containment measures. When considered jointly, however, a cost-equivalent optimal mix allocates 20 percent of the budget to payroll subsidies and 80 percent to UI expansion. This allocation is sufficient to save high-productivity jobs from dissolution, while the remaining funds are used to provide income to less-productive workers who face inevitable job loss.

We abstract away from two potentially important margins. First, we assume away labor mobility across sectors. If the pandemic has a disproportionately persistent effect on labor demand in one of the sectors, policies that tie workers to jobs, such as payroll subsidies, would become less desirable. Second, we abstract away from welfare gains from demand stabilization. Because payroll subsidies and UI policies benefit different groups of people with potentially different marginal propensities to consume, their effects on aggregate demand may be different. We leave these important considerations for future research.

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A Appendix

A.1 Stationary Equilibrium

Let $s \in \{E, N\}$ denote the essential E and nonessential N sectors. A recursive equilibrium for this economy is a list of household and firm policy functions for whether to keep an existing match $d^h_{W,k,s}$, $d^h_{U_T,k,k',s}$, and $d^h_{J,k,s}$; whether to produce or pause l^h_s, $\forall h \in \{S, I, R\}$, $\forall s \in \{E, N\}$, and $\forall k \in \{C, U\}$; labor market tightness θ_s $\forall s \in \{E, N\}$; an aggregate law of motion for the mass of susceptible S, infected I, recovered R, and dead D people; and the distribution of households across states μ such that:

1. Given government policies, household and firm policy functions solve their problems.
2. Labor market tightness in sector s satisfies free-entry condition $V = 0$.
3. Aggregate laws of motion for health status are given by

$$\begin{aligned} S_{t+1} &= S_t - T_t \\ I_{t+1} &= I_t + T_t - \left(\pi^R + \pi^D\right) I_t \\ R_{t+1} &= R_t + \pi^R I_t \\ D_{t+1} &= D_t + \pi^D I_t, \end{aligned} \tag{A1}$$

   where total number of new infections in period t is $T_t = \pi_1 N^S_t N^I_t + \pi_2 S_t I_t$ and N^h is the total number of actively employed households with health status h.

4. μ is the invariant distribution implied by contact rates in the labor market, transition matrices Π_n for health status, P for match-specific productivity, and household and firm decision rules.

A.2 Computational Details

In this section, we describe how we solve and simulate our model.

A.2.1 Steady State

We use value function iteration to solve the worker and firm optimization problems. The algorithm we use to obtain the stationary equilibrium of the model is outlined below.

For a given parameterization of the model and for each sector $s \in \{E, N\}$:

1. Start with an initial guess of market tightness θ^s_0.
2. For each guess of θ^s_n in iteration n:
   (a) Iterate on worker and firm value functions in Equations (2), (3), (6), (7) and (8) until convergence.
   (b) Iterate on the laws of motion implied by the model to compute the stationary worker distribution over employment states, health status and productivity.

(c) Solve the market tightness level $\widetilde{\theta}^s_{n+1}$ that satisfies the free-entry condition $V = 0$, where V is given in Equation (9). Calculate its absolute deviation from θ^s_n.

(d) If the deviation is less than a tolerance level, stop. Otherwise update the guess for market tightness to $\theta^s_{n+1} = \zeta\theta_n + (1-\zeta)\widetilde{\theta}^s_{n+1}$ with dampening parameter $\zeta < 1$ and return to Step 2.

A.2.2 Transition

For each policy, in calculating impulse responses, we focus on perfect foresight transition dynamics following one-time and unanticipated shocks out of steady state, using a shooting algorithm that we outline below.

1. Fix the number of time periods it takes to reach the new steady state, T.

2. Compute the initial (no-infection) steady-state equilibrium for a given set of model parameters according to the algorithm in Section A.2.1. As the epidemic is transitory and there is no permanent productivity difference between susceptible and recovered workers, worker and firm value functions in the terminal steady state are the same as in the initial steady state, as is the labor market tightness for each sector.

3. Guess a sequence of infected worker labor supply and the total number of infected in the economy as a whole, $\{N^{I,0}_t, I^0_t\}^{T-1}_{t=1}$. For each sector $s \in \{E, N\}$:

   (a) Guess a sequence of labor market tightness, $\{\theta^{s,0}_t\}^{T-1}_{t=1}$.

   (b) Solve for the path of worker and firm value functions for $t \in \{1, \ldots, T-1\}$ *backwards*, given the shocks, path of infection $\{N^{I,0}_t, I^0_t\}^{T-1}_{t=1}$, market tightness $\{\theta^{s,0}_t\}^{T-1}_{t=1}$, and terminal worker and firm values in period T.

   (c) Compute the sequence of labor market tightness $\{\theta^{s,1}_t\}^{T-1}_{t=1}$ consistent with the free-entry condition and worker laws of motion over the state space, induced by the decisions implied by the path of value functions over $t \in \{1, \ldots, T-1\}$.

   (d) Check if $\max_{1\le t<T} \ |\theta^{s,1}_t - \theta^{s,0}_t|$ is less than a tolerance level. If yes, continue; if not, update $\{\theta^{s,0}_t\}^{T-1}_{t=1}$ and go back to Step (b).

   (e) Check if $|\theta^{s,1}_T - \theta^{s,0}_T|$ is less than a tolerance level. If yes, stop; if not, increase T and go back to Step 1.

4. Calculate the sequence of infected worker labor supply and the total number of infected, $\{N^{I,1}_t, I^1_t\}^{T-1}_{t=1}$, implied by the path of worker distribution over the transition.

5. Check if $\max_{1\le t<T} \ |N^{I,1}_t - N^{I,0}_t|$ and $\max_{1\le t<T} \ |I^1_t - I^0_t|$ are less than a tolerance level. If yes, continue; if not, update $\{N^{I,0}_t\}^{T-1}_{t=1}$ and $\{I^0_t\}^{T-1}_{t=1}$ and go back to Step 3.

6. Check if $|N^{I,1}_T - N^{I,0}_T|$ and $|I^1_T - I^0_T|$ are less than a tolerance level. If yes, stop; if not, increase T, and go back to Step 1.

A.3 Computing the Statistical Value of Life

To calculate the model-implied statistical value of life (SVL), we first compute the fraction of lifetime consumption π all agents in the steady-state economy are willing to forgo in order to prevent a rise in the probability of death by $\psi = \frac{1}{10{,}000}$. We do this by resolving our no-infection model with a discount factor $\widetilde{\beta} = (1-\psi)\beta$ adjusted by this mortality rate and finding the π that renders workers indifferent between these two economies behind the veil of ignorance.

Second, to convert fraction π to a dollar amount, we take the quarterly consumption amount from the National Income Accounts. U.S. consumption per capita in the fourth quarter of 2019 was $\$40,748$. We divide this number by 52.14 to arrive at a weekly consumption of $c_w^{NIPA} = \$781.5$. The model-implied weekly dollar amount that workers are willing to forgo is then given by $\pi \times c_w^{NIPA}$.

In the final step, we convert the weekly consumption that workers are willing to forgo into a present value term by taking its geometric sum, i.e. $\frac{\pi c_w^{NIPA}}{1-\beta}$. This implies that the total amount that workers are willing to pay to avoid one death is $\frac{1}{\psi}\frac{\pi c_w^{NIPA}}{1-\beta}$, which is the definition of SVL. We choose the constant $\overline{u}$ in the utility function such that $SVL = \$10M$.

A.4 Computing Welfare

To compute a welfare metric, we solve for the percent change in lifetime consumption π that renders a household, behind the veil of ignorance, indifferent between the baseline economy and the economy under a new labor market policy, accounting for all policy changes during the transition period. The expected value of a particular policy p, just as that policy is implemented, is given by

$$\mathbb{E}V(\pi, p) \equiv \sum_{t=1}^{T-1} \beta^{t-1} \left[\int u\left((1+\pi)\, c_{it}(p)\right) d\Lambda_{it}(p) \right] + \beta^{T-1} \int V_{iT}(\pi, p) d\Lambda_{iT}(p),$$

where $c_{it}(p)$ denotes the consumption of individual i under policy p in period t, $\Lambda_{it}(p)$ is the cross-sectional cumulative density function of workers, and $V_{iT}(\pi, p)$ is the steady-state value of individual i, where she receives an additional π percent of her consumption under that policy. The underlying assumption here is that the economy is close enough to its terminal steady state by the end of period T. In practice, we choose $T = 500$ weeks in our computations, which we observe to be long enough for the economy to have converged to a stationary equilibrium.

Finally, to arrive at the welfare metric $\pi(p)$ under policy p, we solve the following condition:

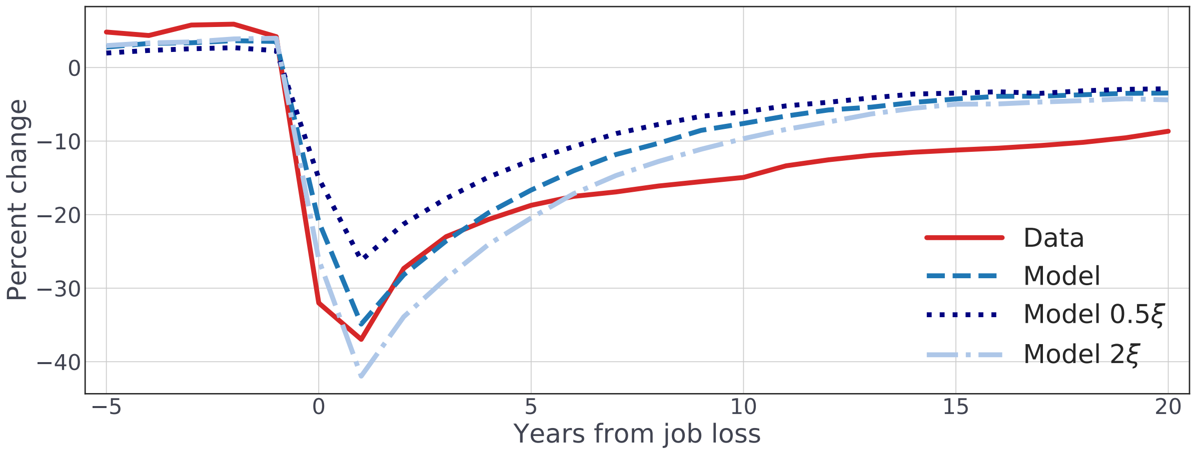
$$\mathbb{E}V(\pi, 0) = \mathbb{E}V(0, p),$$

where we use the convention that $p = 0$ denotes the baseline economy, i.e. there are no fiscal measures introduced. Otherwise, we consider $p \in \{\text{UI}, \text{Payroll}, \text{Mix}\}$ for various policy scenarios.

A.5 Earnings Drop upon Job Loss

To estimate the consequences of job loss for individual earnings, we follow Jacobson et al. (1993) and Stevens (1997), and use a distributed lag regression. We first simulate a weekly panel of workers from the steady state equilibrium of the model. Next, to facilitate a comparison between

Figure A1: Earnings dynamics upon job loss: Data vs model



Notes: This figure plots the earnings dynamics upon job loss. Model results are obtained by estimating a distributed lag regression on annual data simulated from the model. The three series correspond to the following cases i) the baseline calibration (dashed blue line), ii) the economy with the productivity upgrade probability ξ half the baseline value (dotted blue line), and iii) the economy with ξ twice the baseline value (dash-dotted blue line). Empirical estimates are obtained from Jarosch (2015).

the existing empirical estimates and their model counterparts, we aggregate the weekly data from the model into an annual frequency. Finally, we run the following regression on model-generated annual data:

$$y_{it} = \sum_{k \geq -5}^{20} \psi_k D_{it}^k + \alpha_i + \epsilon_{it}. \tag{A2}$$

Here, y_{it} denotes the labor earnings of individual i in year t, and α_i captures individual fixed effects. The vector of dummy variables D_{it}^k indicate an individual's job loss in a future, current, or previous year.[1] For example, $D_{it}^5 = 1$ if individual i lost a job in year $t-5$ and zero otherwise.

We estimate ψ_k for the five years preceding the job loss ($k = -5, -4, -3, -2, -1$), for the year of job loss ($k = 0$), and for every year until 20 years after the job loss ($k = 1, 2, ..., 20$). Here, ψ_k captures the effect on year t earnings of individuals that are displaced k years before/after year t (treatment group). The control group consists of individuals who never experience displacement over the estimation period. Thus, individuals in the control group have $D_{it}^k = 0$ for all years t. In our results below, the earnings drop upon job loss measures the change in the earnings of the treatment group relative to the change in the earnings of the control group. Finally, we report estimated earnings losses ψ_k as a percent of the mean earnings in the year prior to the job loss.

Figure A1 compares the model's predictions with the empirical estimates obtained by Jarosch (2015). Two main points are worth highlighting.

First, even though the baseline calibration did not target the earnings drop upon job loss, its magnitude (35 percent) in the year following the job loss is remarkably close to the data (37 percent), at least to that measured in Jarosch (2015), who uses administrative data from Germany

[1] We obtain yearly earnings by summing weekly earnings. If an individual losses a job during in at least one week of a year, then we set the job loss dummy to one for that year.

to estimate a specification similar to Equation (A2). For the U.S., our estimate is smaller than the estimate in Jacobson et al. (1993) (40 percent) and larger than that in Stevens (1997) (30 percent). Moreover, Davis and von Wachter (2011) and Birinci (2020) estimate the earnings drop upon job loss separately for recessions and expansions. Using administrative data from the U.S., Davis and von Wachter (2011) find larger earnings losses upon displacement in recessions (39 percent) than in expansions (25 percent). Similarly, using the Panel Study of Income Dynamics, Birinci (2020) finds an earnings drop of 39 percent in recessions and 22 percent in expansions in the year following the job loss. To sum up, our model implies an estimate of the earnings drop upon job loss that is within the range of existing estimates for recessions and expansions. That being said, the longer-term effects are understated by around 5 percentage points compared to the data.

Second, we recognize that while the magnitude and persistence of the earnings drop upon job loss in the model are not too far off from the data, these losses in the model are entirely due to match-specific capital, whereas in the data they may also be driven by losses in other forms of human capital (general, occupation-specific, etc.), employer stigma, and so on. In order to understand how differences in the importance of match-specific capital map to optimal policy, in Section 4, we conduct a robustness analysis on ξ. This parameter is the probability that match productivity increases on the job, and therefore controls how important match-specific capital is. We consider two alternative values for this parameter: half (0.5ξ) and double the baseline (2ξ) values. Figure A1 shows that as ξ increases, the earnings drop upon job loss becomes more severe, both in the short- and the long-term. This result arises because a large ξ implies faster productivity growth for the control group over the period when job losers remain unemployed.