Returns to Labor Mobility *

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Abstract

This paper demonstrates how cross-phenomenon restrictions involving returns to labor mobility can guide calibrations of productivity processes in modern macro-labor models. We exploit how returns to labor mobility determine effects on equilibrium unemployment of changes in (a) layoff costs, and (b) likelihoods of skill losses following quits. We study distinct classes of models with theoretical perspectives and associated data sources from (i) labor economics, and (ii) industrial organization. We use them to shine light on calibrations of influential macro-labor studies.

JEL: E24, J63, J64

Keywords: labor mobility, quits, turnover, layoff cost, turbulence, unemployment, human capital, matching model, search model, search-island model.

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1 Introduction

Returns to labor mobility are key intermediating forces in all modern macroeconomic models with frictional labor markets, but sources of evidence for calibrating structural parameters that influence those returns vary across studies. Calibrations of all quantitative macro-labor models rely on evidence about exogenous stochastic processes that determine productivities of new and ongoing employment relationships. In addition, as inputs to calibration, some leading models have used worker flows and unemployment experiences observed by labor economists, including patterns of how different government policies have been related to hazard rates for job-finding and job-separating. Other macro-labor models have used evidence about firm size dynamics assembled by students of industrial organization to restrict calibrations that support structural interpretations of how shocks that ultimately reshape labor reallocations are intermediated through production technologies. Yet again, macroeconomics has been imperialistic in openly seizing data and modeling ideas from other fields, in this case, from labor economics and industrial organization.

Our purpose here is to emphasize how implied returns to labor mobility transcend alternative theoretical perspectives and associated sources of data coming from labor economics and industrial organization. We do that by studying how inferences about returns to labor mobility are affiliated with answers to two questions: (a) how layoff costs affect unemployment; and (b) how higher hazards of human capital loss that coincide with job destructions and quits affect unemployment. By respecting "cross-phenomenon restrictions" that are intimately linked to returns to labor mobility, this paper sheds new light on calibrations of some celebrated macro-labor studies.

Three popular frameworks for studying frictional unemployment are: (1) matching models in the Diamond-Mortensen-Pissarides tradition; (2) equilibrium versions of McCall (1970) search models; and (3) search-island models in the tradition of Lucas and Prescott (1974). Calibrated versions from all three types of models have succeeded in fitting data on labor market flows and generating plausible responses of unemployment rates to government policies like unemployment insurance and layoff taxes. We revisit some of these successes here, keeping our eyes open for implications about returns to labor mobility.

Two leading frameworks for studying effects of layoff taxes on unemployment are the matching model of Mortensen and Pissarides (1999, henceforth MP), who calibrate productivity processes to unemployment statistics and outcomes in an unemployment insurance system; and the search-island model of Alvarez and Veracierto (2001, henceforth AV), who enlist establishment data on firm and worker turnover (Davis and Haltiwanger, 1990) to calibrate firm size dynamics that offer us different perspectives. Thus, AV's growth model intermediates productivity shocks through a neo-classical production function and gives rise to large returns to labor mobility that are robust to calibration details. MP's parameterization also yields the high returns to labor mobility that are compatible with the observation that high layoff taxes do not completely shut down labor reallocation in welfare states. But we have discovered a previously undetected fragility in MP's calibration that is associated with elements of a ridge traced out by two key parameters that, although they have very different implications for returns to labor mobility, can generate the same unemployment statistic targeted by MP. More generally, in macro-labor models not quantitatively motivated by evidence on firm size dynamics and shocks to productivity that are intermediated through production functions, issues arise about whether parameter values yield high enough returns to labor mobility to be consistent with evidence on the substantial labor reallocation observed across diverse market economies.

A second set of insights about an affiliated issue in macro-labor economics that flow from keeping track of returns to labor mobility concerns effects on unemployment of increased hazard rates of human capital losses at times of job separation. Ljungqvist and Sargent (1998, 2008) showed that an increased hazard of human capital losses coincident with *involuntary* job losses ("layoff turbulence") interacted with Europe's more generous welfare states to generate higher and more persistent unemployment rates in Europe than in the US since the late 1970s. Ljungqvist and Sargent (2007, henceforth LS) confirm that the same outcomes arise in a matching model. den Haan, Haefke and Ramey (2005, henceforth DHHR) added human capital losses also coincident with *voluntary* job losses. They showed how adding even a small amount of such "quit turbulence" to their calibrated matching model reverses the unemployment-increasing interactions between turbulence and welfare state generosity. Although den Haan *et al.* didn't discuss what their calibrated model implied about returns to labor mobility, it is enlightening to do so, as we do in this paper. It turns out that for quit turbulence to reverse those unemployment-increasing interactions between turbulence and welfare state generosity, returns to labor mobility must be sufficiently small. Thus, evidence about the returns to labor mobility can shed light on the potential impact of quit turbulence. How might we go about ferreting out pertinent evidence?

To infer quantitatively plausible returns to labor mobility and hence, what could be the potential impact of quit turbulence, we consult a cross-phenomenon restriction that involves effects on unemployment of changes in layoff costs, on the one hand, and changes in quit turbulence, on the other hand. To do this, we proceed by, first, incorporating a consensus view about the order of magnitude of the effects of layoff costs on unemployment to deduce reasonable parameter values for productivity processes, and, then, studying the associated potential impact of quit turbulence on the turbulence-unemployment relationship.

Section 2 sets forth our benchmark model into which we map all productivity processes that we consider. Our benchmark model is a version of an LS matching model augmented to include quit turbulence as in the DHHR model. Using the productivity processes of LS and DHHR as examples of high versus low returns to labor mobility, Section 3 studies the unemployment effects of layoff costs and quit turbulence, respectively. To highlight the generality of how magnitudes of effects of layoff costs and quit turbulence on unemployment are tied together through their common dependence on returns to labor mobility, Section 4 constructs a mapping from the parameters of the productivity process to outcome statistics for layoff costs and quit turbulence, respectively. The statistics are highly correlated. Specifically, in the relevant parameter region where voluntary separations do not shut down under what plausibly represent levels of layoff costs observed in welfare states, reasonable levels of quit turbulence cannot reverse a positive turbulence-unemployment relationship. Besides reaffirming this cross-phenomenon restriction, the mappings of the productivity processes of MP and AV into our benchmark model in Sections 5 and 6, respectively, illustrate how our inferences about returns to labor mobility might depend on whether we approach them while bringing to bear theoretical perspectives and data coming from labor economics or from industrial organization. Section 7 offers some concluding remarks. Auxiliary materials appear in an online Appendix.

2 Benchmark model

Our benchmark is a standard matching model to which we add human capital dynamics that incorporate turbulence. Specifically, we adopt the LS matching model that has 'layoff turbulence' in the form of worse skill transition probabilities for workers who suffer involuntary layoffs. We augment the model to include 'quit turbulence' – worse skill transition probabilities for workers who experience voluntary quits – as in the DHHR model.[1]

2.1 Environment

Workers There is a unit mass of workers who are either employed or unemployed. Workers are risk neutral, value consumption, and have preferences ordered according to

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t c_t. \tag{1}$$

They discount future utilities at a rate $\beta \equiv \hat{\beta}(1-\rho^r)$, where $\hat{\beta} \in (0,1)$ is a subjective time discount factor and $\rho^r \in (0,1)$ is a constant probability of retirement. A retired worker exits the economy and is replaced by a newborn worker.

[1]LS thanked Wouter den Haan, Christian Haefke, and Garey Ramey for generously sharing computer code that LS then modified. Much of our notation and mathematics follow DHHR closely. For an account of differences between the models of LS and DHHR, see Appendix A.

Worker heterogeneity Besides employment status, workers differ along two dimensions: a current skill level i that can be either low (l) or high (h) and a skill level j that determines a worker's entitlement to unemployment benefits. An employed worker has $j = i$, but for an unemployed worker, j is the skill level during her last employment spell. Workers gain or lose skills depending on their employment status and instances of layoffs and quits. We assume that all newborn workers enter the labor force with low skills and a low benefit entitlement. In this way, each worker bears two indices (i, j), the first denoting current skill and the second denoting benefit entitlement.

Firms and matching technology There is free entry of firms who can post vacancies at a cost μ per period. Aggregate numbers of unemployed u and vacancies v are inputs into an increasing, concave and linearly homogeneous matching function $M(v, u)$. Let $\theta \equiv v/u$ be the vacancy-unemployment ratio, also called market tightness. The probability $\lambda^w(\theta) = M(v, u)/u = M(\theta, 1) \equiv m(\theta)$ that an unemployed worker encounters a vacancy is increasing in market tightness. The probability $M(v, u)/v = m(\theta)/\theta$ that a vacancy encounters an unemployed worker is is decreasing in market tightness.

Worker-firm relationships and productivity processes A job opportunity is a productivity draw z from a distribution $v_i^o(z)$ that is indexed by a worker's skill level i. We assume that the high-skill distribution first-order stochastically dominates the low-skill distribution: $v_h^o(z) \leq v_l^o(z)$. Wages are determined through Nash bargaining, with π and $1 - \pi$ as the bargaining weights of a worker and a firm, respectively.

Idiosyncratic shocks within a worker-firm match determine an employed worker's productivities. Productivity in an ongoing job is governed by a first-order Markov process with a transition probability matrix Q_i, also indexed by the worker's skill level i, where $Q_i(z, z')$ is the probability that next period's productivity becomes z', given current productivity z. Specifically, an employed worker retains her last period productivity with probability $1 - \gamma^s$, but with probability γ^s draws a new productivity from the distribution $v_i(z)$. As in the case of the productivity distributions for new matches, the high-skill distribution in ongoing jobs first-order stochastically dominates the low-skill distribution: $v_h(z) \leq v_l(z)$. Furthermore, an employed worker's skills may get upgraded from low to high with probability γ^u. A skill upgrade is accompanied by a new productivity drawn from the high-skill distribution $v_h(z)$. A skill upgrade is realized immediately, regardless of whether the worker remains with her present employer or quits.

We can now define our notions of layoffs and quits.

(i) **Layoffs:** At the beginning of each period, a job is exogenously terminated with probability ρ^x. We call this event a layoff. An alternative interpretation of the job-termination probability ρ^x is that productivity z becomes zero and stays zero forever. A layoff is involuntary in the sense of offering no choice.

(ii) **Quits:** As a consequence of a new productivity draw on a job and possibly a skill upgrade, a relationship can continue or be endogenously terminated. We label separation after such an event a voluntary quit because a firm and a worker agree to separate after Nash bargaining.

Turbulence We define turbulence as the risk of losing skills after a job separation. High-skilled workers might become low-skilled workers. Two types of turbulence shocks depend on the reason for a job separation, namely, a layoff or a quit. Upon a layoff, a high-skilled worker experiences a skill loss with probability $\gamma^{d,x}$. We label this risk *layoff turbulence*. Upon a quit, a high-skilled worker faces the probability γ^d of a skill loss. We label this risk *quit turbulence*.

Turbulence shocks are timed as follows. At the beginning of a period, exogenous job terminations occur and displaced workers face layoff turbulence. Continuing employed workers can experience new productivity draws on the job and skill upgrades; if workers quit, they are subject to quit turbulence. All separated workers join other unemployed workers in the matching function where they might or might not encounter vacancies next period.

Government policy The government provides unemployment compensation. An unemployed worker who was low (high) skilled in her last employment receives a benefit b_l (b_h).[2] Unemployment benefit b_i is calculated as a fraction ϕ of the average wage of employed workers with skill level i. The government imposes a layoff tax Ω on every job termination except for retirements.

The government runs a balanced budget by levying a flat-rate tax τ on production. If layoff tax revenues fully cover payments of unemployment benefits, the government sets $\tau = 0$ and returns any surplus as lump-sum transfers to workers. Since the latter will not happen in our analyses, we omit such lump-sum transfers in our expressions below.

2.2 Match surpluses

A match between a firm and a worker with skill level i and benefit entitlement j that has drawn productivity z will form an employment relationship, or continue an existing one, if a match surplus is positive. The match surplus for a new job $s^o_{ij}(z)$ or a continuing job $s_{ij}(z)$ is given by the after-tax productivity $(1-\tau)z$ plus the future joint continuation value $g_i(z)$ minus the outside values of the match that consist of the worker's receiving unemployment benefit b_j and

[2] As mentioned above, newborn workers are entitled to b_l. Also, for simplicity, we assume that a worker who receives a skill upgrade and chooses to quit, is entitled to high benefits.

a future value ω_{ij}^w associated with entering the unemployment pool in the current period; and the firm's value ω^f from entering the vacancy pool in the current period, net of paying the vacancy cost μ. For notational simplicity, we define $\omega_{ij} \equiv \omega_{ij}^w + \omega^f$.

The match surplus for a new job $s_{lj}^o(z)$ or a continuing job $s_{lj}(z)$ with a low-skilled worker with benefit entitlement j is given by

$$s_{lj}^o(z) \;=\; s_{lj}(z) \;=\; (1-\tau)z + g_l(z) - [b_j + \omega_{lj}], \qquad j = l, h. \tag{2}$$

To compute the match surplus for jobs with high-skilled workers, we must distinguish between new and continuing jobs. The match surplus when forming a new job with an unemployed high-skilled worker, s_{hh}^o, involves outside values without any risk of skill loss if the match does not result in employment:

$$s_{hh}^o(z) \;=\; (1-\tau)z + g_h(z) - [b_h + \omega_{hh}]. \tag{3}$$

In contrast, the match surplus for a continuing job with a high-skilled worker or for a job with an earlier low-skilled worker who gets a skill upgrade that is immediately realized involves quit turbulence:

$$s_{hh}(z) \;=\; (1-\tau)z + g_h(z) - [b_h + \underbrace{(1-\gamma^d)\omega_{hh} + \gamma^d \omega_{lh}}_{\text{quit turbulence}}]. \tag{4}$$

Reservation productivities and rejection rates A worker and a firm split the match surplus through Nash bargaining with outside values as threat points. The splitting of match surpluses ensures mutual agreement whether to start (continue) a job. For a new (continuing) match, the reservation productivity $\underline{z}_{ij}^o$ ($\underline{z}_{ij}$) is the lowest productivity that makes a match profitable and satisfies

$$s_{ij}^o(\underline{z}_{ij}^o) \;=\; 0 \qquad \Big(s_{ij}(\underline{z}_{ij}) \;=\; -\Omega\Big). \tag{5}$$

Note that in a continuing match the surplus must fall to the negative of the layoff tax before a job is terminated.

Given the reservation productivity $\underline{z}_{ij}^o$ ($\underline{z}_{ij}$), let ν_{ij}^o (ν_{ij}) denote the rejection probability, which is given by the probability mass assigned to all draws from productivity distribution $v_i^o(y)$ ($v_i(y)$) that fall below the threshold:

$$\nu_{ij}^o \;=\; \int_{-\infty}^{\underline{z}_{ij}^o} dv_i^o(y) \qquad \left(\nu_{ij} \;=\; \int_{-\infty}^{\underline{z}_{ij}} dv_i(y)\right). \tag{6}$$

To simplify formulas below, we define

$$E_{ij} \equiv \int_{\underline{z}_{ij}}^{\infty} [(1-\tau)y + g_i(y)] \; dv_i(y). \tag{7}$$

2.3 Joint continuation values

Consider a match between a firm and a worker with skill level i. Given a current productivity z, $g_i(z)$ is the joint continuation value of the associated match. We now characterize value functions for low- and high-skilled workers.

High-skilled worker The joint continuation value of a match of a firm with a high-skilled worker with current productivity z, denoted $g_h(z)$, is affected by future layoff turbulence if the worker is laid off or by future quit turbulence if a productivity switch is rejected:

$$\begin{array}{llcl}
\text{Exogenous separation:} & g_h(z) & = & \beta\Big[\rho^x(b_h + \underbrace{(1-\gamma^{d,x})\omega_{hh} + \gamma^{d,x}\omega_{lh}}_{\text{layoff turbulence}}) \\
\text{Productivity switch:} & & + & (1-\rho^x)\gamma^s(E_{hh} + \nu_{hh}(b_h + \underbrace{(1-\gamma^d)\omega_{hh} + \gamma^d\omega_{lh}}_{\text{quit turbulence}})) \\
\text{No changes:} & & + & (1-\rho^x)(1-\gamma^s)((1-\tau)z + g_h(z))\Big].
\end{array} \tag{8}$$

Low-skilled worker The joint continuation value of a match of a firm with a low-skilled worker takes into account the following contingencies: no changes in productivity or skills, an exogenous separation, a productivity switch, and a skill upgrade. When a skill upgrade occurs, a worker immediately become entitled to high unemployment benefits, even if the worker quits. Furthermore, a skill upgrade coincides with a new draw from the high-skill productivity distribution v_h. Thus, the joint continuation value of a match between a firm and a low-skilled worker with current productivity z is

$$\begin{array}{llcl}
\text{Exogenous separation:} & g_l(z) & = & \beta\Big[\rho^x(b_l + \omega_{ll}) \\
\text{Immediate skill upgrade:} & & + & (1-\rho^x)\gamma^u(E_{hh} + \nu_{hh}(b_h + \underbrace{(1-\gamma^d)\omega_{hh} + \gamma^d\omega_{lh}}_{\text{quit turbulence}})) \\
\text{Productivity switch:} & & + & (1-\rho^x)(1-\gamma^u)\gamma^s(E_{ll} + \nu_{ll}(b_l + \omega_{ll})) \\
\text{No changes:} & & + & (1-\rho^x)(1-\gamma^u)(1-\gamma^s)((1-\tau)z + g_l(z))\Big].
\end{array} \tag{9}$$

2.4 Outside values

Value of unemployment An unemployed worker with current skill level i and benefit entitlement j receives benefits b_j and has a future value ω^w_{ij}. Recall that the probability that an unemployed worker becomes matched next period is $\lambda^w(\theta)$.

A low-skilled unemployed worker with benefit entitlement j obtains $b_j + \omega^w_{lj}$, where

$$\omega^w_{lj} \;=\; \beta\Big[\underbrace{\lambda^w(\theta)\int_{\underline{z}^o_{lj}}^{\infty} \pi s^o_{lj}(y)\; dv^o_l(y)}_{\text{match + accept}} \quad + \underbrace{b_j + \omega^w_{lj}}_{\text{outside value}}\Big] \qquad j = l, h. \tag{10}$$

A high-skilled unemployed worker with benefit entitlement h, obtains $b_h + \omega^w_{hh}$, where

$$\omega^w_{hh} \;=\; \beta\Big[\underbrace{\lambda^w(\theta)\int_{\underline{z}^o_{hh}}^{\infty} \pi s^o_{hh}(y)\; dv^o_h(y)}_{\text{match + accept}} \quad + \underbrace{b_h + \omega^w_{hh}}_{\text{outside value}}\Big]. \tag{11}$$

Value of a vacancy A firm that searches for a worker pays an upfront cost μ to enter the vacancy pool and thereby obtains a fraction $(1-\pi)$ of the match surplus if an employment relationship is formed next period. Let $\lambda^f_{ij}(\theta)$ be the probability of filling the vacancy with an unemployed worker of type (i, j). Then a firm's value ω^f of entering the vacancy pool is:

$$\omega^f \;=\; -\mu + \beta\Big[\underbrace{\sum_{(i,j)} \lambda^f_{ij}(\theta)\int_{\underline{z}^o_{ij}}^{\infty} (1-\pi) s^o_{ij}(y)\; dv^o_i(y)}_{\text{match + accept}} \quad + \underbrace{\omega^f}_{\text{outside value}}\Big]. \tag{12}$$

2.5 Market tightness and matching probabilities

Let u_{ij} be the number of unemployed workers with current skill i and benefit entitlement j. The total number of unemployed workers is $u = \sum_{i,j} u_{ij}$. The probability $\lambda^w(\theta)$ that an unemployed worker encounters a vacancy is function only of market tightness θ; the probability $\lambda^f_{ij}(\theta)$ that a vacancy encounters an unemployed worker with skill level i and benefit entitlement j also depends on the worker composition in the unemployment pool. Free entry of firms implies that a firm's expected value of posting a vacancy is zero. Equilibrium market tightness can be deduced from equation (12) with $w^f = 0$. We summarize these labor market outcomes as follows:

$$
\begin{aligned}
\omega^f &= 0 && (13)\\
\mu &= \beta(1-\pi)\sum_{(i,j)} \lambda^f_{ij}(\theta)\int_{\underline{z}^o_{ij}}^{\infty} s^o_{ij}(y)\; dv^o_i(y) && (14)\\
\lambda^w(\theta) &= m(\theta) && (15)\\
\lambda^f_{ij}(\theta) &= \frac{m(\theta)}{\theta}\frac{u_{ij}}{u}\,. && (16)
\end{aligned}
$$

2.6 Wages

When computing wages, we assume standard Nash bargaining between a worker and a firm each getting their shares of the match surplus in every period.[3] Given a productivity draw z in a new match with a positive match surplus, the wage $p^o_{lj}(z)$ of a low-skilled worker with benefit entitlement $j = l, h$ and the wage $p^o_{hh}(z)$ of a high-skilled worker, respectively, solve the following maximization problems:

$$
\begin{aligned}
&\max_{p^o_{lj}(z)} \quad \left[(1-\tau)z - p^o_{lj}(z) + g^f_l(z) - \omega^f\right]^{1-\pi}\left[p^o_{lj}(z) + g^w_l(z) - b_j - \omega^w_{lj}\right]^{\pi} && (17)\\
&\max_{p^o_{hh}(z)} \quad \left[(1-\tau)z - p^o_{hh}(z) + g^f_h(z) - \omega^f\right]^{1-\pi}\left[p^o_{hh}(z) + g^w_h(z) - b_h - \omega^w_{hh}\right]^{\pi},
\end{aligned}
$$

where $g^w_i(z)$ and $g^f_i(z)$ are future values obtained by the worker and the firm, respectively, from continuing the employment relationship;[4] and ω^f and $b_j + \omega^w_{ij}$ are outside values defined in (10), (11), and (12). The solution to the wage determination problems sets the sum of the worker's wage and continuation value equal to the worker's share π of the match surplus plus her outside value:

$$
\begin{aligned}
p^o_{lj}(z) + g^w_l(z) &= \pi s^o_{lj}(z) + b_j + \omega^w_{lj} && j = l, h && (18)\\
p^o_{hh}(z) + g^w_h(z) &= \pi s^o_{hh}(z) + b_h + \omega^w_{hh},
\end{aligned}
$$

[3]An implication of the Nash bargaining assumption is that workers pay part of the layoff tax upon a job separation. An alternative assumption is that once a worker is hired, firms are the only ones liable for the layoff tax. This generates a two-tier wage system à la Mortensen and Pissarides (1999). Risk neutral firms and workers would be indifferent between adhering to period-by-period Nash bargaining or a two-tier wage system. As demonstrated by Ljungqvist (2002), the wage profile, not the allocation, is affected by the two-tier wage system. Match surpluses, reservation productivities, and market tightness remain the same. Under the two-tier wage system, an initial wage concession by a newly hired worker is equivalent to her posting a bond that equals her share of a future layoff tax.

[4]*Joint* continuation values defined in (8) and (9) equal sums of the individual continuation values: $g_i(z) = g^w_i(z) + g^f_i(z),\; i = l, h$.

where the worker continuation values are

$$\begin{aligned}
g_l^w(z) &= \beta(1-\rho^x)\pi\left\{(1-\gamma^u)\left[(1-\gamma^s)s_{ll}(z)+\gamma^s\int_{\underline{z}_{ll}}^{\infty}s_{ll}(y)\ dv_l(y)\right]+\gamma^u\int_{\underline{z}_{hh}}^{\infty}s_{hh}(y)\ dv_h(y)\right\} \\
&+ \beta(\rho^x+(1-\rho^x)(1-\gamma^u))\left(b_l+\omega_{ll}^w\right)+\beta(1-\rho^x)\gamma^u\left(b_h+(1-\gamma^d)\omega_{hh}^w+\gamma^d\omega_{lh}^w\right) \qquad (19) \\
g_h^w(z) &= \beta(1-\rho^x)\pi\left[(1-\gamma^s)s_{hh}(z)+\gamma^s\int_{\underline{z}_{hh}}^{\infty}s_{hh}(y)\ dv_h(y)\right] \\
&+ \beta\rho^x\left(b_h+(1-\gamma^{d,x})\omega_{hh}^w+\gamma^{d,x}\omega_{lh}^w\right)+\beta(1-\rho^x)\left(b_h+(1-\gamma^d)\omega_{hh}^w+\gamma^d\omega_{lh}^w\right).
\end{aligned}$$

For ongoing employment relationships, the wages $p_{ll}(z), p_{hh}(z)$ satisfy counterparts of the above equations that use the corresponding match surpluses $s_{ll}(z)$ and $s_{hh}(z)$:

$$\begin{aligned}
p_{ll}(z)+g_l^w(z) &= \pi s_{ll}(z)+b_l+\omega_{ll}^w \qquad (20) \\
p_{hh}(z)+g_h^w(z) &= \pi s_{hh}(z)+b_h+\underbrace{(1-\gamma^d)\omega_{hh}^w+\gamma^d\omega_{lh}^w}_{\text{quit turbulence}},
\end{aligned}$$

where the latter expression for the high-skilled wage now involves quit turbulence on the right side.

2.7 Government budget constraint

Unemployment benefits Benefit entitlement j awards an unemployed worker benefit b_j equal to a fraction ϕ of the average wage $\bar{p}_j$ of employed workers with skill level j. Therefore, total government expenditure on unemployment benefits amounts to

$$b_l u_{ll}+b_h(u_{lh}+u_{hh})=\phi(\bar{p}_l u_{ll}+\bar{p}_h(u_{lh}+u_{hh})). \qquad (21)$$

Layoff taxes Let Ξ be total separations excluding retirements, which are equal to

$$\Xi=(1-\rho^r)\Big[\rho^x(e_{ll}+e_{hh})+(1-\rho^x)[(1-\gamma^u)\gamma^s\nu_{ll}+\gamma^u\nu_{hh}]e_{ll}+(1-\rho^x)\gamma^s\nu_{hh}e_{hh}\Big]. \qquad (22)$$

Then government revenue from layoff taxation equals $\Omega\,\Xi$.

Income taxes Output is taxed at a constant rate τ. Let $\bar{z}_i$ be the average productivity of employed workers with skill level i. Hence, total tax revenue equals $\tau(\bar{z}_l e_{ll}+\bar{z}_h e_{hh})$, where e_{ll} (e_{hh}) is the number of employed workers with low skills and low benefit entitlement (high skills and high benefit entitlement).

Balanced budget The government runs a balanced budget. The tax rate τ on output is set to cover the expenditures on unemployment benefits described in (21) net of layoff tax revenues $\Omega\,\Xi$:

$$\phi(\bar{p}_l u_{ll} + \bar{p}_h(u_{lh} + u_{hh})) - \Omega\,\Xi = \tau(\bar{z}_l e_{ll} + \bar{z}_h e_{hh}). \tag{23}$$

For computations of average wages $\bar{p}_i$ and average productivities $\bar{z}_i$, see Appendix B.2.

2.8 Worker flows

Workers move across employment and unemployment states, skill levels, and benefit entitlement levels. Here we focus on a group of workers at the center of our analysis: low-skilled unemployed with high benefits. (Appendix B.1 describes flows for other groups of workers.)

Inflows to the low-skilled unemployed with high benefits u_{lh} occur in the following situations. Layoff turbulence affects high-skilled workers e_{hh} who get laid off; with probability $\gamma^{d,x}$, they become part of the low-skilled unemployed with high benefit entitlement. Quit turbulence affects high-skilled workers e_{hh} who reject productivity switches, as well as low-skilled workers e_{ll} who get skill upgrades and then reject their new productivity draws. All of those quitters face probability γ^d of becoming part of the low-skilled unemployed with high benefit entitlement. Outflows from unemployment occur upon successful matching function encounters and retirements. Thus, the net change of low-skilled unemployed with high benefits (equalling zero in a steady state) becomes:

$$\begin{aligned}\Delta u_{lh} \;=\; (1-\rho^r)\Big\{ & \underbrace{\rho^x \gamma^{d,x} e_{hh}}_{\text{1. layoff turbulence}} + \underbrace{(1-\rho^x)\gamma^d \nu_{hh}[\gamma^s e_{hh} + \gamma^u e_{ll}]}_{\text{2. quit turbulence}} \\ & - \underbrace{\lambda^w(\theta)(1-\nu^o_{lh})u_{lh}}_{\text{3. successful matches}} \Big\} - \rho^r u_{lh}. \end{aligned} \tag{24}$$

Terms numbered 1 and 3 in expression (24) isolate the forces behind the positive turbulence-unemployment relationship in a welfare state in the LS model. Although more layoff turbulence in term 1 – a higher probability $\gamma^{d,x}$ of losing skills after layoffs – has a small effect on equilibrium unemployment in a laissez-faire economy, it gives rise to a strong turbulence-unemployment relationship in a welfare state that offers a generous unemployment benefit replacement rate on a worker's earnings in her last employment. After a layoff with skill loss, those benefits are high relative to a worker's earnings prospects at her now diminished skill level. As a consequence, the acceptance rate $(1-\nu^o_{lh})$ in term 3 is low; because of the relatively high outside value of a low-skilled unemployed with high benefits, fewer matches have positive match surpluses, as reflected in a high reservation productivity z^o_{lh}. Moreover, given those suppressed match surpluses, equilibrium market tightness θ falls to restore firm profitability enough to make vacancy creation break even. Lower market tightness, in turn, reduces the probability $\lambda^w(\theta)$ that a worker encounters a vacancy, which further suppresses successful matches and contributes to the positive turbulence-unemployment relationship.

The assumption of quit turbulence adds the term numbered 2 in expression (24) that exerts a countervailing force against the positive turbulence-unemployment relationship described above. When higher turbulence is associated with voluntary quits that are also subject to risks of skill loss, there will be a lower incidence of voluntary quits in turbulent times because the risk of skill loss makes high-skilled workers more reluctant to quit. This makes the rejection rate ν_{hh} in term 2 become low in turbulent times. That lower rejection rate causes lower inflows into low-skilled unemployed with high benefits u_{lh} as well as into high-skilled unemployed with high benefits u_{hh}. This force might reverse the positive turbulence-unemployment relationship.

2.9 Steady state equilibrium

A steady state equilibrium consists of measures of unemployed u_{ij} and employed e_{ij}; a labor market tightness θ, probabilities $\lambda^w(\theta)$ that workers encounter vacancies and $\lambda^f_{ij}(\theta)$ that vacancies encounter workers; reservation productivities $\underline{z}^o_{ij}, \underline{z}_{ij}$, match surpluses $s^o_{ij}(z), s_{ij}(z)$, future values of an unemployed worker ω^w_{ij} and of a firm posting a vacancy ω^f; wages $p^o_{ij}(z), p_{ij}(z)$; unemployment benefits b_i and a tax rate τ; such that

a) Match surplus conditions (5) determine reservation productivities.

b) Free entry of firms implies zero-profit condition (14) in vacancy creation that pins down market tightness.

c) Nash bargaining outcomes (18) and (20) set wages.

d) The tax rate balances the government's budget (23).

e) Net worker flows, such as expression (24), are all equal to zero: $\Delta u_{ij} = \Delta e_{ij} = 0, \quad \forall\, i, j$.

2.10 Parameterization

Apart from considering alternative assumptions about the productivity process and different values of the layoff tax, the benchmark model shares the remaining parameterization with LS, in conjunction with DHHR's codification of quit turbulence, as reported in Table 1.[5] The model period is half a quarter.

[5]Subject to the caveat of DHHR assuming a fixed population of firms of the same measure as that of workers and hence, an exogenous market tightness equal to 1, the remaining parameterization in Table 1 is identical or similar to that of DHHR. For a detailed account, see Appendix A.

Table 1: PARAMETERIZATION OF BENCHMARK MODEL

Parameter	Definition	Value
Preferences		
$\hat{\beta}$	discount factor	0.99425
ρ^r	retirement probability	0.0031
$\beta = \hat{\beta}(1 - \rho^r)$	adjusted discount	0.991
Sources of risk		
ρ^x	exogenous breakup probability	0.005
γ^u	skill upgrade probability	0.0125
γ^s	productivity switch probability	0.05
$\gamma^{d,x}$	layoff turbulence	$[0, 1]$
$\gamma^d = \epsilon\gamma^{d,x}$	quit turbulence	$\epsilon \in [0, 1]$
Labor market institutions		
π	worker bargaining power	0.5
ϕ	replacement rate	0.7
Ω	layoff tax	0
Matching function		
A	matching efficiency	0.45
α	elasticity of matches w.r.t. u	0.5
μ	cost of posting a vacancy	0.5

Preference parameters Given a semi-quarterly model period, we specify a discount factor $\hat{\beta} = 0.99425$ and a retirement probability $\rho^r = 0.0031$, which together imply an adjusted discount of $\beta = \hat{\beta}(1 - \rho^r) = 0.991$. The retirement probability implies an average time of 40 years in the labor force.

Stochastic processes for productivity Exogenous layoffs occur with probability $\rho^x = 0.005$, on average a layoff every 25 years. We set a probability of upgrading skills $\gamma^u = 0.0125$ so that it takes on average 10 years to move from low to high skill, conditional on no job loss. The probability of a productivity switch on the job equals $\gamma^s = 0.05$, so a worker expects to retain her productivity for 2.5 years.

Layoff and quit turbulence Following DHHR, we parameterize quit turbulence as a fraction ϵ of layoff turbulence, and we vary it from zero – only layoff turbulence – to one – the two types of turbulence are equal: $\gamma^d = \epsilon\gamma^{d,x}$.

Labor market institutions We set a worker's bargaining power to be $\pi = 0.5$. We set the replacement rate in unemployment compensation at $\phi = 0.7$ and the layoff tax at $\Omega = 0$ (where the latter is to be perturbed in our investigation of returns to labor mobility).

Matching We assume a Cobb-Douglas matching function $M(v, u) = Au^{\alpha}v^{1-\alpha}$, which implies that the probability of a worker encountering a vacancy and the probability of a vacancy encountering a particular worker type, respectively, are:

$$\lambda^w(\theta) = A\theta^{1-\alpha}, \qquad \lambda^f_{ij}(\theta) = A\theta^{-\alpha}\frac{u_{ij}}{u}. \tag{25}$$

The elasticity of matches with respect to unemployment is specified to be $\alpha = 0.5$ in accordance with a consensus about plausible values falling in the mid range of the unit interval (e.g., see the survey of Petrongolo and Pissarides (2001)). We adopt LS's parameterization of the matching efficiency $A = 0.45$ and the cost of posting a vacancy $\mu = 0.5$.

3 High (LS) vs low (DHHR) returns to labor mobility

As examples of productivity distributions that imply high versus low returns to labor mobility, we use the parameterizations of LS and DHHR as reported in the first two columns of Table 2 and depicted in Figure 1. Both LS and DHHR assume productivity distributions that are the same for new and ongoing matches, $v_i^o(z) = v_i(z)$. LS parameterize truncated normal distributions in Figure 1a whereas DHHR in Figure 1b assume uniform distributions with narrow ranges.[6] The implied returns to labor mobility manifest in how equilibrium unemployment responds to layoff taxes and quit turbulence, respectively. We start by conducting those analyses in the original models of LS and DHHR, and then map each productivity process into our benchmark model under the assumption of uniform distributions. The latter mappings enable us to project the findings from LS and DHHR onto an entire space of productivity processes in Section 4, and thereby highlight the generality of a cross-phenomenon restriction with respect to the unemployment effects of layoff taxes on the one hand, and quit turbulence on the other hand.

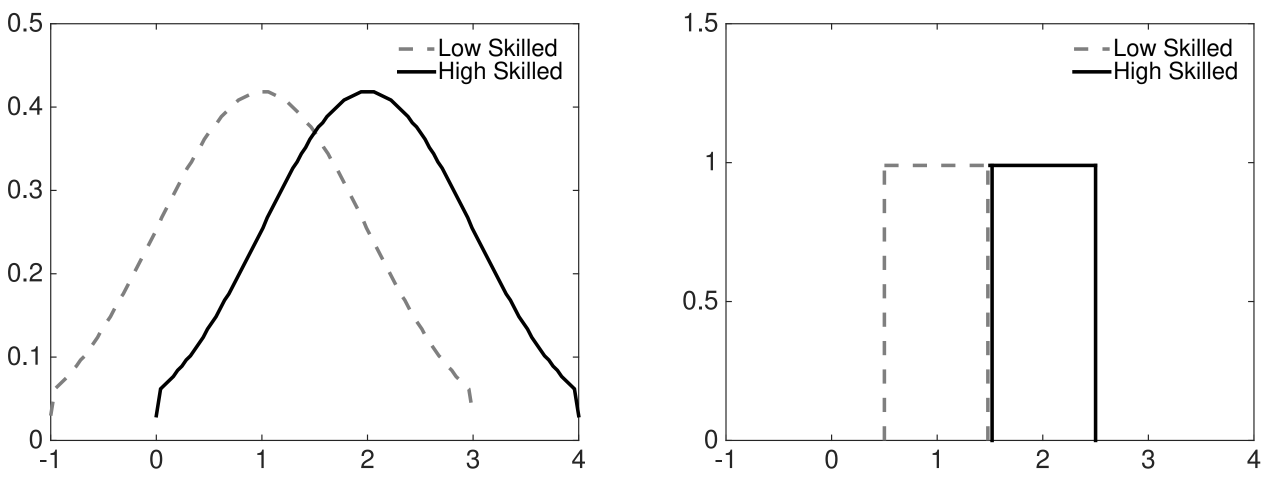
The original model of LS is obtained by simply importing the LS productivity distributions into our benchmark model. What we refer to as the DHHR model is their original framework except for two modifications that do not alter outcomes substantially, although they do facilitate

[6]LS incorrectly implemented the quadrature method at the truncation points of the normal distributions; nevertheless, the constructed distributions are still proper. Therefore, instead of recalibrating the LS model under a correct implementation of the quadrature method, we have chosen for reasons of comparability to retain the distributions presented in the published LS analysis.

Table 2: Productivity distributions of LS and DHHR

Properties	**Original model** LS	**Original model** DHHR	**Benchmark model version** LS	**Benchmark model version** DHHR
Functional form, $v_i(z)$	Normal	Uniform	Uniform	Uniform
Mean, low-skilled	1	1	1	1
high-skilled	2	2	2	2
Width of support	4	1	2.25	0.6
Standard deviation	1	0.289	0.650	0.173

Figure 1: Productivity distributions of LS and DHHR



(a) LS (Normal with wide support)

(b) DHHR (Uniform with narrow support)

our subsequent way of mapping DHHR into our benchmark model.[7] Regarding our analyses of the unemployment effects of layoff taxes, we de facto replicate computations by LS while the analysis in the DHHR model is new and reveals low returns to labor mobility. Regarding our analyses of the unemployment effects of quit turbulence, we mimic and expand on DHHR's finding that small levels of quit turbulence reverse the Ljungqvist-Sargent unemployment-increasing interactions between turbulence and welfare state generosity, while showing that not to be the case in the LS model with its higher returns to labor mobility.

Next, we map the models of LS and DHHR into our benchmark model under the assumption of uniform distributions. In the case of LS, it is a question of only converting LS's truncated normal distributions into uniform distributions. For DHHR, things acre more complicated because their matching framework differs from our benchmark model in two substantive but, for our purposes, inconsequential ways.[8] Hence, it turns out that the mapping of DHHR into our benchmark model also comes down to only a conversion of DHHR's productivity distributions. Specifically, we calibrate the width of support for the uniform distributions in the benchmark model to generate unemployment effects of quit turbulence similar to those in our analyses of the LS and DHHR model, respectively. As predicated by a cross-phenomenon restriction, the unemployment effects of layoff taxes for each calibration of the benchmark model will then also be in concordance with outcomes in our corresponding analyses of the LS and DHHR model, respectively.

3.1 Layoff taxes

Layoff taxes in LS In the LS model without turbulence, Figure 2 shows unemployment and rejection rates by type of worker, as well as aggregate labor flows, as functions of the layoff tax Ω. The layoff tax is expressed as a fraction of the average yearly output per worker in the laissez-faire economy.[9] The unemployment rate falls as the layoff tax increases. Employed

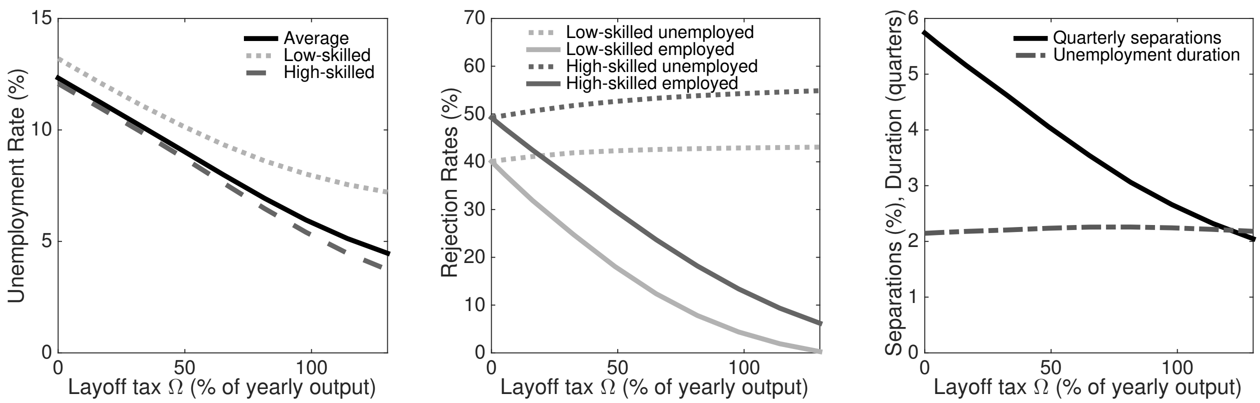
[7]Our first modification is that instead of the zero benefits that they receive in the original DHHR setup, we assume that newborn workers are eligible for the same unemployment benefits as low-skilled workers. The second modification concerns the risk of losing skills following unsuccessful job market encounters. As a "simplifying assumption," DHHR assume that after an encounter between a firm and an unemployed worker that does not result in an employment relationship, the worker faces the same risk of losing skills as she would after quitting a job; an added risk that we omit. For an assessment of these alternative assumptions, see Appendix D.

[8]As detailed in Appendix A, these structural differences pertain to i) how vacancies are created, and ii) how the capital gain from a skill upgrade is split between firm and worker. To show that among these two differences and the parameterization of productivity distributions it is the latter one that is the sole important source for how unemployment responds to quit turbulence, we proceed as follows. Appendix C starts with the benchmark model with LS productivity distributions in Figure 4a below and successively perturbs the three potential sources one by one, to see which one brings us closest to outcomes in the DHHR model in Figure 4b. In Appendix D, we start from the DHHR model in Figure 4b and work through the perturbations in reverse. Both procedures detect productivity distributions as being the critical source for differences in outcomes.

[9]In the LS laissez-faire economy, a worker's average semi-quarterly output is 2.3 goods in tranquil zero-turbulence times.

workers, both high- and low-skilled, are especially affected by the layoff tax as their rejection rates fall significantly. Nevertheless, these workers remain mobile even with rather large layoff taxes. For example, if the layoff tax reaches the average annual output of a worker, employed high-skilled workers reject about 12% of offers.

Figure 2: Layoff taxes in LS



Incidentally, Figure 2 illustrates LS's explanation for a welfare state's having lower unemployment than a laissez-faire economy in tranquil times (i.e., before the onset of economic turbulence). In a matching model, countervailing forces emanating from unemployment benefits and layoff taxes can explain why the unemployment rate in a welfare state need not be high (also see Mortensen and Pissarides (1999)). Despite generous unemployment benefits with a replacement rate of $\phi = 0.7$, layoff taxes at the right end of the first panel in Figure 2 cause unemployment to fall below the laissez-fare rate of 5%.

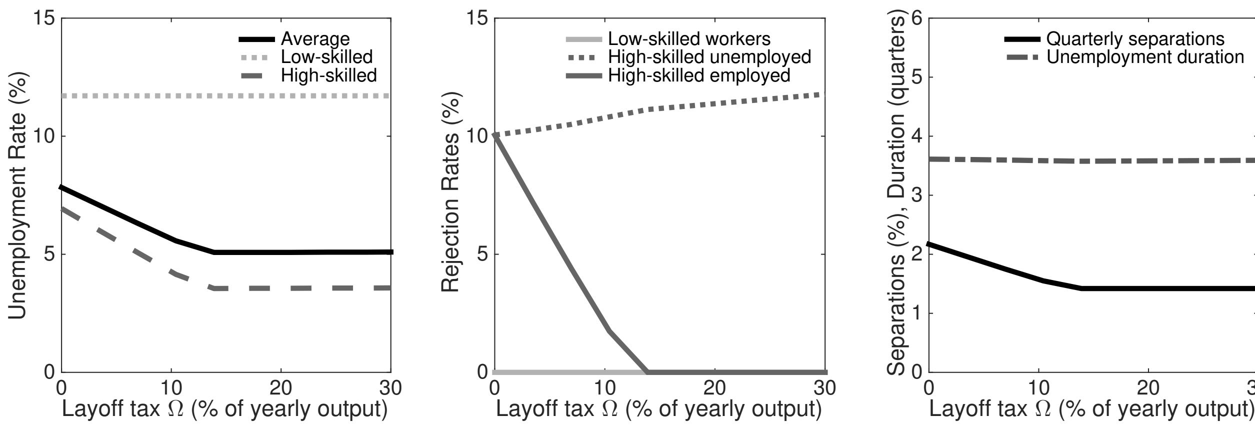
For later use, we note that endogenous separations in the LS model shut down completely when the layoff tax reaches 184% of the average yearly output per worker. This can be discovered by extrapolating the dark solid curve in the middle panel of Figure 2; evidently, high-skilled employees are most resilient before eventually stopping to quit. The corresponding minimum layoff tax required to close down all endogenous separations in the laissez-faire economy with no unemployment insurance is 163%. Without unemployment compensation, the gains from quitting and searching for another job are smaller so that it requires a smaller layoff tax to shut down endogenous separations in the laissez-faire economy.

Layoff taxes in DHHR We introduce a layoff cost Ω in the DHHR model.[10] Figure 3 shows how a higher layoff tax affects equilibrium outcomes in the DHHR model without turbulence. Mobility of high-skilled employed completely shuts down at a layoff tax equivalent to 14% of the

[10]Besides our two simplifying modifications of the original DHHR framework in footnote 7, we here assume that skill upgrades are realized immediately in the DHHR model as in the LS framework. Appendix D.2 documents a small impact on equilibrium outcomes in the DHHR model of such a change in assumptions.

average annual output per worker in the laissez-faire economy.[11] Above this low level of layoff taxes, the rejection rate of these workers becomes zero and separation rates become constant at exogenous job termination rates. Imposing a small layoff tax eradicates the value of labor mobility. Note that for both employed and unemployed low-skilled workers, the rejection rate is zero for the DHHR parameterization at all levels of the layoff tax.

Figure 3: LAYOFF TAXES IN DHHR



It is noteworthy that there are no endogenous separations at all in the corresponding laissez-faire economy of DHHR. So endogenous separations occur in our DHHR model only because they are encouraged by a generous replacement rate of $\phi = 0.7$.

3.2 Quit turbulence

How should a model represent the uncontroversial observation that different job separators find themselves in different situations? For example, workers with valuable skills who separate in order to find better-paying jobs differ from laid-off workers whose skills are no longer in demand, e.g., due to changing technologies or their types of work moving abroad to low-wage countries.

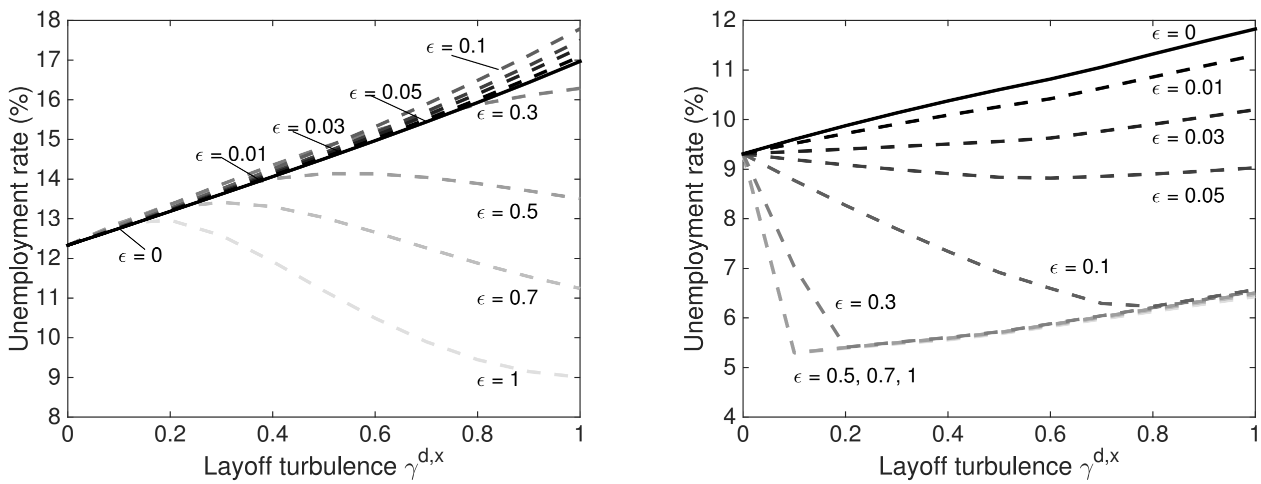
To capture such differences, the benchmark model treats involuntary separations as earlier theories did by assuming that they lead to the most unfavorable circumstances for job separators in the sense that they present the highest risks of skill losses. In addition to such layoff turbulence, following DHHR, the benchmark model introduces quit turbulence for workers who voluntarily separate from jobs after draws of poor job-specific productivities at their current employment. Workers who voluntarily separate are ones with more favorable situations both in terms of having an opportunity to continue working after shocks to productivity at their current employment, as well as, conditional on separating, facing a lower risk of skill loss than do workers who suffer involuntary separations.

[11]In the DHHR laissez-faire economy, a worker's average quarterly output is 1.8 goods in tranquil zero-turbulence times.

Within this setup and following DHHR, we can investigate how robust the turbulence theory's imputation of high and persistent European unemployment to interactions between microeconomic turbulence and Europe's more generous welfare states is to introducing quit turbulence. We can accomplish this by measuring how much the risk of skill loss at times of voluntary separations must be relative to the risk at times of involuntary separations in order to generate a negative rather than a positive turbulence-unemployment relationship. Because contending forces push for and against the turbulence theory, this is a quantitative issue, as described in Section 2.8.

When the productivity distributions of the benchmark model are assumed to be those of LS, the unemployment outcomes as a function of turbulence are depicted in Figure 4a. The x-axis shows layoff turbulence $\gamma^{d,x}$ and the y-axis the unemployment rate in percent. Each line has its own quit turbulence γ^d represented as a fraction ϵ of layoff turbulence, i.e., $\gamma^d = \epsilon\gamma^{d,x}$ where $\epsilon \in \{0, 0.01, 0.03, 0.05, 0.1, 0.3, 0.5, 0.7, 1\}$. In Figure 4a, we observe that quit turbulence needs to be high, about 50% of layoff turbulence, before the aggregate unemployment rate starts varying negatively with turbulence, and then only for relatively high levels of layoff turbulence.

Figure 4: Quit turbulence in LS and DHHR



(a) LS model (b) DHHR model

Layoff turbulence $\gamma^{d,x}$ on the x-axis. Each line represents a different quit turbulence γ^d as a fraction ϵ of layoff turbulence, i.e., $\gamma^d = \epsilon\gamma^{d,x}$. Panel a shows the benchmark model with LS productivity distributions, i.e., the LS model with no layoff tax. Panel b is the DHHR model with our two simplifying modifications in footnote 7.

In contrast, DHHR assert a lack of robustness of the turbulence theory because they find that the turbulence-unemployment relationship already becomes negative at very low skill loss probabilities for voluntary separators relative to those for involuntary separators:

"... allowing for a skill loss probability following [voluntary] separation that is

> only 3% of the probability following [involuntary] separation eliminates the positive turbulence-unemployment relationship. Increasing this proportion to 5% gives rise to a strong *negative* relationship between turbulence and unemployment." (DHHR, p. 1362)

Subject to our two modifications of the original DHHR model in footnote 7, we reproduce DHHR's findings in Figure 4b. Evidently, DHHR's assertion remains essentially intact – it just requires a somewhat bigger quit turbulence to generate DHHR's key findings of a negative turbulence-unemployment relationship. For example, as quoted above for the original DHHR model, the relationship becomes markedly negative at 5% of quit turbulence ($\epsilon = 0.05$), while subject to our modifications, quit turbulence needs to be 7% ($\epsilon = 0.07$).

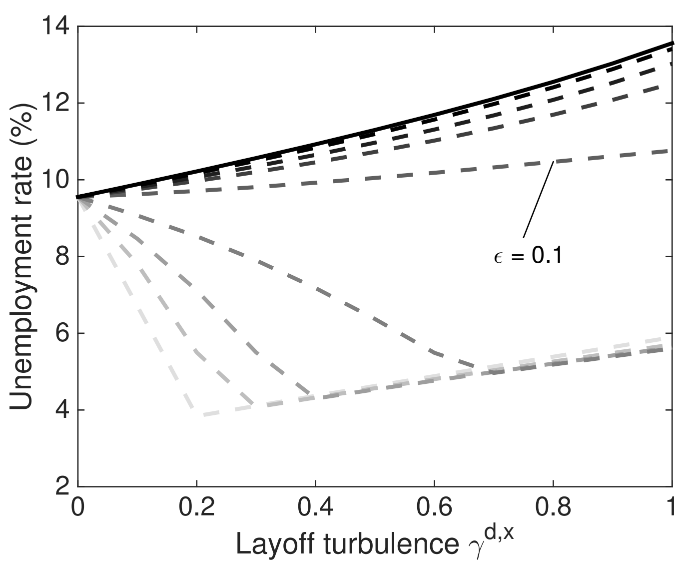
The forces at work are as follows. Productivity draws on the job bring incentives for workers to change employers in search of higher productivities. The small dispersion of productivities under DHHR's uniform distributions with narrow support in Figure 1b make returns to labor mobility be very low. As can be seen in Figure 4b, those low returns do not compensate for even small amounts of quit turbulence and hence the initially positive turbulence-unemployment relationship at zero quit turbulence ($\epsilon = 0$) turns negative at relatively small levels of quit turbulence. In particular, high-skilled workers choose to remain on the job and accept productivities at the lower end of the support of the productivity distribution rather than quit and have to face even small probabilities of skill loss.

We also observe in Figure 4b that DHHR's negative turbulence-unemployment relationship can eventually turn positive, as starkly illustrated by a quit turbulence of $\epsilon = 0.3$ and higher. Those high levels of quit turbulence are initially characterized by a steep negative relationship that comes to an abrupt end, then a kink that is succeeded by a gentler upward-sloping turbulence-unemployment relationship. At kinks, all endogenous separations have shut down. The source of unemployment suppression – reductions in quits – has evaporated. What leads to a positive turbulence-unemployment relationship is that higher turbulence generates more low-skilled unemployed who are entitled to high benefits. For two reasons, these workers must draw relatively high productivities in order to want to join employment relationships. First, compared to low-skilled workers who are entitled to low benefits, such workers are reluctant to give up their high benefits: a stronger bargaining position comes with their high benefits. Second, a bargained wage must not only be high enough to induce those workers to surrender their high benefits; it also must be low enough to induce firms to fill vacancies. As described earlier, DHHR assume a given measure of firms, and each idle firm can be thought of as being endowed with a vacancy. Hence, the opportunity cost for a firm in the above kind of encounter is the option value of waiting to fill the vacancy later because it anticipates the prospect of meeting either a low-skilled unemployed worker who has less bargaining power (i.e., one who is entitled only to low benefits) or a high-skilled unemployed worker. For these two reasons, productivities drawn for low-skilled unemployed workers with high benefits have to be relatively high in order for there to exist a bargained wage that is mutually beneficial for a worker and a firm. The resulting lower hazard rate of escaping unemployment for low-skilled workers with high benefits means that unemployment has to increase with turbulence after all endogenous separations have shut down.

3.3 Benchmark model versions of LS and DHHR

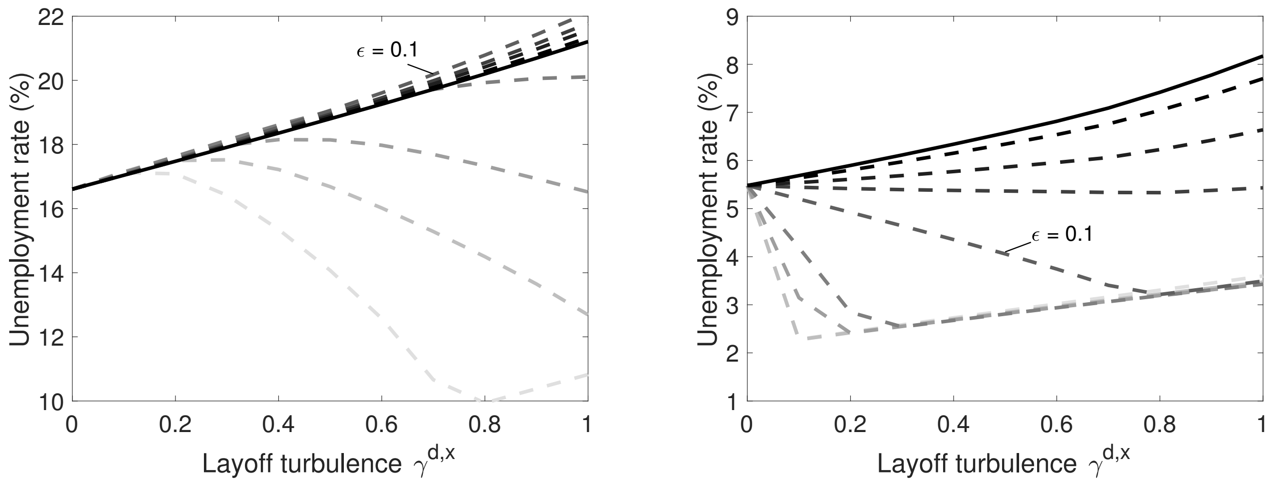
What can explain the dramatically different implications of quit turbulence in the two models analyzed in Figure 4? The answer from our investigation, as described in footnote 8, is that these differences are driven by assumptions about the productivity process. Indeed, by simply switching from the LS to DHHR productivity distributions in the benchmark model, outcomes in Figure 4a morph into those of Figure 5: the positive turbulence-unemployment relationship is weakened so much that we get DHHR-like outcomes. To arrive at what we call the benchmark model version of DHHR, we shrink the width of support of the uniform productivity distributions from DHHR's original value of 1 to 0.6. The result is Figure 6b where the responses of unemployment to layoff and quit turbulence are strikingly similar to those of the DHHR model in Figure 4b. The similarity occurs despite our having preserved the other two structural differences between the models in Figures 6b and 4b, as detailed in footnote 8.

Figure 5: Benchmark model with DHHR productivity distributions



Analogously, we seek a benchmark model version of LS, under the assumption of uniform productivity distributions. As one would expect, given the high returns to labor mobility in the LS model, the mapping requires a fairly large width of support equal to 2.25 for the

Figure 6: Benchmark model versions of LS and DHHR



(a) Benchmark version of LS

(b) Benchmark version of DHHR

uniform distributions. The resulting Figure 6a provides a good fit in terms of generating unemployment responses to turbulence similar to those of the LS model in Figure 4a. While we target only implications of turbulence to calibrate the benchmark model versions of LS and DHHR, respectively, a cross-phenomenon restriction should ensure that the corresponding implications of layoff taxes also hold up in the mappings, as will be born out in the next section.

4 Cross-phenomenon restriction

To bring out the generality of the cross-phenomenon restriction that emerged in our investigation of LS and DHHR, we now characterize the unemployment effects of layoff costs and quit turbulence, respectively, in an entire space of productivity processes. This confirms that the power of layoff costs to reduce unemployment is correlated with how effectively quit turbulence reverses a positive turbulence-unemployment relationship. In both cases, that potency is greater the smaller are the returns to labor mobility as implied by the productivity process. Hence, outcome statistics for layoff costs and quit turbulence, respectively, are positively correlated throughout the space of productivity processes.

Using the benchmark model we generate this characterization in the space of productivity processes delineated by uniform distributions and indexed by the dispersion (standard deviation) as well as the arrival rate γ^s of productivity shocks in continuing matches. We choose the outcome statistic for layoff costs to be the minimum layoff cost for which all voluntary separations shut down in tranquil times ($\gamma^{d,x} = 0$). The layoff cost is expressed as a proportion of the annual output per worker in the corresponding laissez-faire economy. Conditional on a magnitude of layoff turbulence $\gamma^{d,x}$, we choose the outcome statistic for quit turbulence to be the minimum stance of quit turbulence that makes the turbulence-unemployment relationship negative. Quit turbulence is measured relative to the magnitude of layoff turbulence, namely, the fraction $\epsilon \in [0,1]$. So, conditional on a value of $\gamma^{d,x}$, the quit turbulence statistic is the minimum value of ϵ that yields a negative turbulence-unemployment relationship, i.e., the unemployment rate falls with an incremental increase in layoff turbulence at the conditioned value of $\gamma^{d,x}$. (When the turbulence statistic equals the maximum value of 1, it is either a knife-edged case of an interior solution when the minimum value of ϵ that yields a negative turbulence-unemployment relationship occurs at 1 or, more likely, a corner solution in which there exists no $\epsilon \in [0,1]$ that can overturn the positive turbulence-unemployment relationship.)

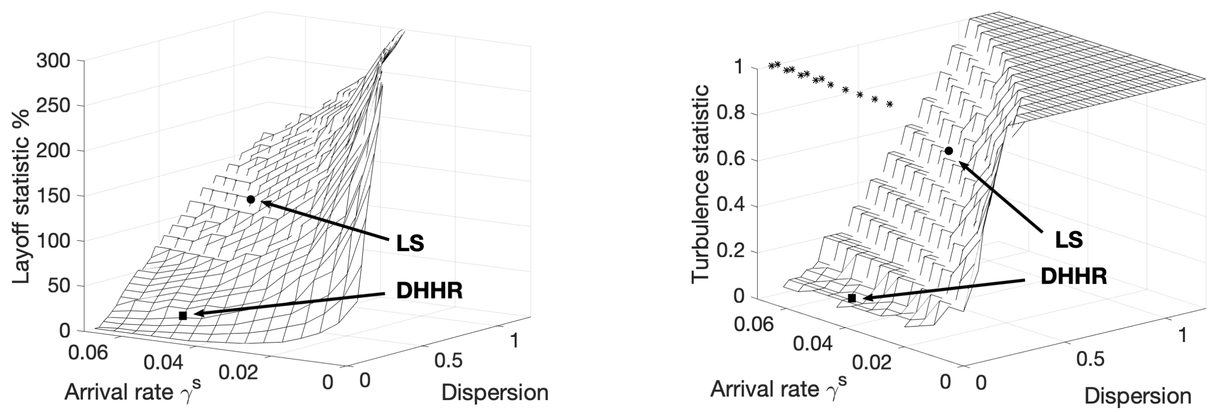
The two outcome statistics are shown in Figure 7.[12] Regarding the layoff cost statistic in Figure 7a, the minimum layoff tax necessary for shutting down voluntary separations is increasing in dispersion and decreasing in the arrival rate. A higher dispersion coincides with higher returns to labor mobility so that a higher layoff cost is required to shut down voluntary separations. A higher arrival rate of productivity shocks in continuing matches implies a lower expected duration of a productivity draw which suppresses returns to labor mobility for two reasons. First, a relatively low productivity draw becomes less costly to bear when it is expected to persist for a shorter period of time. Second, the prospective gain from quitting and finding another match with higher productivity becomes less attractive when the new productivity draw is expected to last for a shorter period of time. These two reasons explain why the minimum layoff tax needed to shut down voluntary separations decreases in the arrival rate. In the far right corner of Figure 7a with high dispersion and very small arrival rates, the layoff cost statistic explodes when the graph is extended. What is happening here is that the supports of the uniform productivity distributions in Figure 1b reach ever deeper into negative territory; combined with a low arrival rate, any poor productivity draw is expected to last for a long time. Consequently, firms are willing to incur very high layoff costs to terminate exceptionally poor productivity draws.[13]

The quit turbulence statistic in Figure 7b, conditional on $\gamma^{d,x} = 0.3$, shows outcomes that clearly are correlated with those of the layoff cost statistic in Figure 7a. The reason for the similarity is that both outcome statistics are driven by the returns to labor mobility implied by the productivity process. It is this interrelatedness of the effects of layoff costs and quit

[12] All outcome statistic figures are drawn for dispersion greater than 0.0722 (a support of 0.25). By omitting zero dispersion, we stay clear of economies that trivially have no endogenous separations. In such degenerate economies, the layoff cost statistic is zero and all turbulence statistics are equal to 1 since, in the absence of quits, there is no force that could reverse the positive turbulence-unemployment relationship.

[13] As a point of reference, the axis for dispersion ends at 1.2 in the outcome statistic figures, which implies a width of just above 4 for the support of the uniform distributions. Thus, at a dispersion of 1.2, the combined productivity distributions for low- and high-skilled workers cover the entire range of the x-axis in Figure 1b.

Figure 7: Cross-phenomenon restriction



(a) Layoff cost statistic

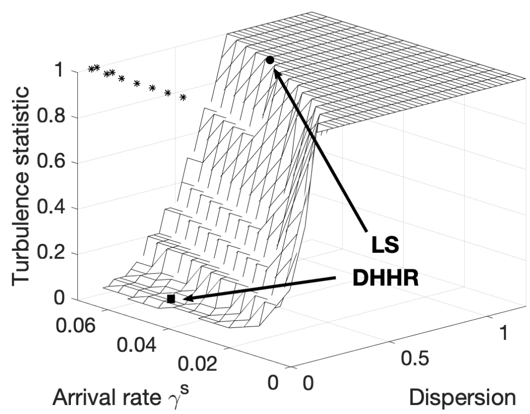
(b) Quit turbulence statistic, $\gamma^{d,x} = 0.3$

turbulence that we call a cross-phenomenon restriction. A difference between the two panels in Figure 7 is that the quit turbulence statistic plateaus at a maximum value of 1 when rates of return to labor mobility are so high that there exists no amount of quit turbulence that can reverse the positive turbulence-unemployment relationship. For a different reason, there are stars at the level of $\epsilon = 1$ for very low values of dispersion in Figure 7b. Here, for a given arrival rate, sufficiently small dispersion implies rates of return to labor mobility so low that even in the absence of quit turbulence there are no voluntary separations. Thus, without any voluntary separations from the outset, there is nothing to be shut down by introducing quit turbulence and hence no force is present to reverse a positive turbulence-unemployment relationship.

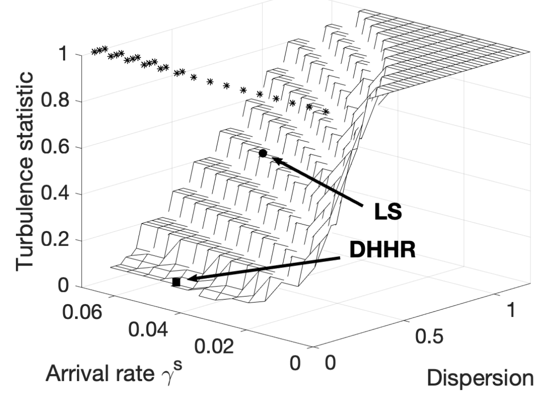
The dependence of the quit turbulence statistic on the level of layoff turbulence $\gamma^{d,x}$ is conveyed in Figure 8. A lower layoff turbulence $\gamma^{d,x} = 0.1$ in Figure 8a implies a steeper slope that hastens the ascent to the plateau where there is no amount of quit turbulence that can reverse the positive turbulence-unemployment relationship, while a higher layoff turbulence $\gamma^{d,x} = 0.5$ in Figure 8b slows down the ascent. At very low dispersions, the two panels show corresponding decreases and increases in the numbers of stars, respectively.

Figures 7 and 8 include two points denoted LS and DHHR, respectively, that are benchmark model versions of those frameworks in the present space of productivity processes that were generated above in Figure 6. For both frameworks, the arrival rate is $\gamma^s = 0.05$ as reported in Table 1, while the dispersion was chosen to target turbulence-unemployment outcomes in each respective framework. Recall that the width of support for the uniform distributions in the benchmark model version of DHHR is 0.6 and hence the dispersion (standard deviation) is equal to $\sqrt{0.6^2/12} = 0.173$; the corresponding numbers for the benchmark model version of LS are a width of support of 2.25 and hence a dispersion equal to 0.650. In accordance with Figure 6b,

Figure 8: Quit turbulence statistic, $\gamma^{d,x} = 0.1$ versus $\gamma^{d,x} = 0.5$



(a) $\gamma^{d,x} = 0.1$



(b) $\gamma^{d,x} = 0.5$

the quit turbulence statistic for DHHR is very low at around 0.05 for all three values of $\gamma^{d,x}$ in Figures 7b, 8a and 8b, respectively. Likewise, the outcomes for LS are ones to be inferred from Figure 6a; specifically, the quit turbulence statistic equals 0.58 at layoff turbulence $\gamma^{d,x} = 0.3$, 1 at the lower value of $\gamma^{d,x} = 0.1$, and 0.45 at the higher value of $\gamma^{d,x} = 0.5$. These all do a good job of representing quit turbulence outcomes in Figure 4 that we set out to explain.[14]

The cross-phenomenon restriction portrayed in Figures 7 and 8 is useful when evaluating the potential for the injection of quit turbulence to undermine the turbulence-theoretic explanation of trans-Atlantic unemployment experiences. Starting with the DHHR analysis, its location in the space of productivity processes confirms our earlier assessment of a most extreme parameterization. Not only does DHHR's productivity process conflict with observations on layoff costs and unemployment, it rests perilously downstream on the border of a parameter region with no voluntary separations (marked by stars). Hence, a small parameter perturbation could paradoxically turn DHHR's feeble positive turbulence-unemployment relationship into an ironclad one. Moving upstream to the other side of DHHR's parameterization would quickly raise the quit turbulence statistic before reaching a parameter region consistent with observations on layoff costs and unemployment; considering higher values of layoff turbulence $\gamma^{d,x}$ provides little relief. Also, any candidate pair $(\gamma^{d,x}, \epsilon)$ for a negative turbulence-unemployment relationship,

[14]For the record, the layoff cost statistics in Figure 7a for the benchmark model versions of DHHR and LS are 23% and 129%, respectively, while the corresponding numbers are 14% and 186% in our layoff cost analyses in Section 3.1. The different numbers for the DHHR framework are due to the structural differences between the benchmark model version and the DHHR model described in footnote 8. In the case of LS, the difference is solely driven by the uniform productivity distributions in the benchmark model version of LS versus LS's own assumption of truncated normal distributions. Not surprisingly, it takes a higher layoff cost to shut down voluntary separations under the latter distributions with longer tails that include worse productivities than the narrower support of the uniform distributions. For our present argument, these differences are immaterial.

would have to be evaluated in terms of its *absolute* level of quit turbulence, $\gamma^d = \epsilon\gamma^{d,x}$. Based on Figures 7 and 8, we conclude that in the present space of productivity processes, the amount of quit turbulence required to reverse the positive turbulence-unemployment relationship is implausibly high. In contrast, the LS analysis falls within a mainstream parameter region in terms of its implied returns to labor mobility, as illustrated in the following analyses.

In the next two sections, we explore two celebrated labor-macro studies of layoff costs – MP's matching model and AV's search-island model. In both frameworks, implicit returns to labor mobility are sufficiently high to be consistent with observed labor market outcomes. Hence, based on our cross-phenomenon restriction, we expect and confirm that those two models imply a positive turbulence-unemployment relationship that is robust to plausible calibrations of quit turbulence. Besides illustrating how the cross-phenomenon restriction transcends the choice of theoretical framework, we compare two distinct perspectives and associated sources of data: one from labor economics and another from the economics of industrial organization.

5 Returns to labor mobility in MP

Mortensen and Pissarides (1999), MP, also study how skill dynamics can interact with welfare-state institutions in a matching model. But in contrast to the benchmark model, MP assume that individual workers are permanently attached to their skill levels and focus on effects of a mean preserving spread of the cross section distribution of skills across workers. To capture 'directed search,' MP assume different matching functions for each skill level.

For us, a key object of the MP model is a probability distribution of idiosyncratic productivities that multiply workers' skills in ongoing matches. MP assume that distribution function is uniform on support $[z^{min}, 1]$ so that the cumulative density is $F(z) = (z - z^{min})/(1 - z^{min})$ for all $z \in [z^{min}, 1]$. As in the benchmark model, productivity shocks in ongoing matches arrive at an exogenous rate γ^s. But in contrast to the benchmark model, new matches have productivity equal to the upper support of the distribution.

MP's parameterization in Table 3 gives the same arrival rate of productivity switches as in the benchmark model, i.e., MP's quarterly probability $\gamma^s = 0.1$ is consistent with the semi-quarterly probability $\gamma^s = 0.05$ in Table 1. Because the narrow range of the support of MP's uniform distribution $[0.64, 1]$ is in the same ballpark as the benchmark model version of DHHR in Table 2, one might expect returns to labor mobility in the MP model to be as small as those of DHHR. However, all new matches in the MP model have productivity equal to the upper support of the distribution, which enhances returns to labor mobility as compared to DHHR's assumption that a new match draws a productivity from the same distribution as continuing matches. Thus, the question is a quantitative one – a question that will also compel us to investigate the calibration approach chosen by MP.

Table 3: MP's parameter values (central to our study)

Parameter	Definition	Value
z^{min}	minimum productivity	0.64
γ^s	productivity switch probability (at a quarterly frequency)	0.1

5.1 Mapping MP's productivity process into benchmark model

Our criterion for faithfully mapping the MP productivity process into the benchmark model is how closely the resulting economy resembles MP's (1999, Table 2a) findings on how unemployment responds to unemployment insurance and layoff taxes as reproduced in the first panel of our Table 4. The fit cannot be perfect since, for example, the benchmark model has two skill levels while MP choose to conduct their calculations for the case of a single skill level equal to 1. Another difference is that MP assume a training cost while the benchmark model has none.

As an intermediate step, we compute outcomes in a perturbed version of the benchmark model with several features modified to be the same as in MP. Specifically, the perturbed benchmark model has only low-skilled workers (with skills equal to one), no exogenous breakups $\rho^x = 0$, an added value of leisure equal to 0.28, and MP's productivity process with $z^{min} = 0.64$. The efficiency factor on the matching function is calibrated to be $A = 0.66$ in order to keep our target of 5 percent unemployment in the laissez-faire economy. The unemployment outcomes of the perturbed benchmark model in the second panel of Table 4 are almost the same as those of MP in our first panel. However, a noticeable difference is that benchmark model unemployment cannot become zero since there is exogenous retirement with probability $\rho^r = 0.0031$. Hence, the influx of new workers in the benchmark model means that the unemployment rate can never fall below 0.3 percent and will be higher if the average time to find a job for newcomers exceeds one semi-quarterly model period.

Encouraged by the success of our intermediate step in approximating MP's unemployment outcomes, we turn to the full-fledged version of the benchmark model with two skill levels, low-skilled and high-skilled workers with skills equal to 1 and 2, respectively. We restore the exogenous breakup probability $\rho^x = 0.005$ and set the value of leisure to zero. In short, we adopt the exact parameterization of the benchmark model in Table 1 while assuming the MP productivity process with $z^{min} = 0.6$.[15] Also, we re-calibrate the efficiency factor on the matching function to be $A = 0.37$ in order to have 5 percent unemployment in the laissez-faire

[15] Since there is no pretense of trying to exactly reproduce MP's unemployment outcomes, we have rounded off the parameter value $z^{min} = 0.6$. A parameter that we will subject to a sensitivity analysis in the next subsection.

Table 4: Unemployment Rate Effects of the UI Replacement Ratio (ϕ) and Layoff Tax (Ω)

Mortensen and Pissarides (1999, Table 2a)

	$\phi = 0.0$	$\phi = 0.1$	$\phi = 0.2$	$\phi = 0.3$	$\phi = 0.4$	$\phi = 0.5$
$\Omega = 0.0$	4.8	5.5	6.2	7.3	9.0	11.9
$\Omega = 0.5$	3.7	4.3	5.0	5.9	7.5	10.3
$\Omega = 1.0$	2.5	2.9	3.5	4.4	5.7	8.4
$\Omega = 1.5$	1.1	1.5	1.9	2.6	3.6	5.9
$\Omega = 2.0$	0.0	0.0	0.0	0.0	1.3	2.9

Perturbed version of benchmark model with only low-skilled workers

	$\phi = 0.0$	$\phi = 0.1$	$\phi = 0.2$	$\phi = 0.3$	$\phi = 0.4$	$\phi = 0.5$
$\Omega = 0.0$	5.0	5.5	6.2	7.2	8.6	11.0
$\Omega = 0.5$	4.2	4.6	5.2	6.0	7.2	9.2
$\Omega = 1.0$	3.2	3.6	4.1	4.8	5.9	7.6
$\Omega = 1.5$	2.2	2.5	2.9	3.5	4.4	5.9
$\Omega = 2.0$	1.1	1.3	1.7	2.1	2.8	3.9
$\Omega = 2.5$	0.4	0.5	0.5	0.6	1.0	1.8

A perturbed version of the benchmark model with only low-skilled workers, no exogenous breakups $\rho^x = 0$, an added value of leisure equal to 0.28, and MP's productivity process with $z^{min} = 0.64$. Matching efficiency is calibrated to $A = 0.66$. Layoff taxes Ω are expressed in terms of quarterly output.

Benchmark model with the MP productivity process

	$\phi = 0.0$	$\phi = 0.1$	$\phi = 0.2$	$\phi = 0.3$	$\phi = 0.4$	$\phi = 0.5$	$\phi = 0.6$	$\phi = 0.7$
$\Omega = 0.0$	5.0	5.4	5.8	6.4	7.0	7.8	8.8	10.2
$\Omega = 1.0$	3.9	4.2	4.5	5.0	5.5	6.2	7.1	8.4
$\Omega = 2.0$	3.0	3.3	3.6	4.0	4.5	5.1	5.9	7.0
$\Omega = 3.0$	2.1	2.3	2.6	3.0	3.4	3.9	4.5	5.5
$\Omega = 4.0$	1.3	1.3	1.5	1.8	2.2	2.6	3.1	3.9
$\Omega = 5.0$	1.3	1.3	1.4	1.5	1.6	1.7	1.8	2.3

The benchmark model with MP's productivity process with $z^{min} = 0.6$. Matching efficiency is calibrated to $A = 0.37$. Layoff taxes Ω are expressed in terms of quarterly output.

economy.

The third panel of Figure 4 contains outcomes of our full-fledged version of the benchmark model with the MP productivity process. Now our comparison to MP's outcomes in the first panel has to be more subtle and bring to bear adjustments beyond those to the retirement rate deployed in our intermediate step. First, in our two-skill economy, the steady-state labor force consists of 20 percent low-skilled and 80 percent high-skilled workers. Thus, the layoff tax numbers in the third panel would have to be cut approximately in half to be comparable to the first two panels when expressing layoff taxes relative to workers' output since high-skilled workers who make up the vast majority of the labor force in the third panel are twice as productive as the workers of the first two panels. Because the layoff taxes reported in the third panel are twice as high as those reported in the first two panels, we can compare outcomes line-by-line across panels. Second, the assumption of a value of leisure equal to 0.28 for workers with skill level one in the first two panels lets us convert that into an extra replacement rate in unemployment insurance of 0.3 in the third panel. Thus, a replacement rate ϕ in the first two panels would correspond to a replacement rate of $\phi + 0.3$ in the third panel. Third, the last panel can be thought of as having calibrated a laissez-faire unemployment rate of 6.4 percent, as given by column $\phi = 0.3$ (and no layoff tax), because a replacement rate $\phi = 0.3$ would represent only the value of leisure according to our conversion argument. A way to correct for this concocted elevated unemployment rate of the laissez-faire calibration is to deduct from each computed unemployment rate an adjustment equal to the difference between the third panel's column $\phi = 0.3$ and column $\phi = 0$, i.e., a single adjustment for each value of the layoff tax. As an illustration, these adjustments would turn the unemployment rates in column $\phi = 0$ into the new numbers of column $\phi = 0.3$.

The preceding three adjustments intended to make the third panel comparable to the first two panels are implemented in Table 5, including a re-labelling of replacement rates to become $\hat{\phi} = \phi - 0.3$ and layoff taxes to become $\hat{\Omega} = 0.5\,\Omega$. Evidently, our mapping of MP into the benchmark model is quite successful when comparing Table 5 to the MP outcomes in the first panel of Figure 4. However, differences appear at higher layoff taxes at which the higher unemployment rates of the benchmark model can largely be attributed to its exogenous rates of retirements $\rho^r = 0.0031$ and of breakups $\rho^x = 0.005$. Since our intermediate step includes the retirement rate but not the exogenous breakup rate, it is understandable that unemployment outcomes at higher layoff taxes in the second panel of Table 4 fall between the lower and higher unemployment rates of MP in the first panel of Table 4 and the benchmark model in Table 5, respectively. Apparently, at such high layoff taxes, endogenous separations have either shut down or are about to in all of the economies so that unemployment becomes driven mostly by exogenous shocks of separation.

Table 5: Assessing the success of mapping MP into benchmark model

Adjusted version of the benchmark model with the MP productivity process

	$\hat{\phi} = 0.0$	$\hat{\phi} = 0.1$	$\hat{\phi} = 0.2$	$\hat{\phi} = 0.3$	$\hat{\phi} = 0.4$	Adj. factor
$\hat{\Omega} = 0.0$	5.0	5.6	6.4	7.4	8.8	1.4
$\hat{\Omega} = 0.5$	3.9	4.4	5.1	6.0	7.3	1.1
$\hat{\Omega} = 1.0$	3.0	3.5	4.1	4.9	6.0	1.0
$\hat{\Omega} = 1.5$	2.1	2.5	3.0	3.6	4.6	0.9
$\hat{\Omega} = 2.0$	1.3	1.7	2.1	2.6	3.4	0.5
$\hat{\Omega} = 2.5$	1.3	1.4	1.5	1.6	2.1	0.2

5.2 Fragility of MP's calibration

In conducting the quantitative analysis of the preceding subsection, we encountered a fragility in how MP had restricted the calibration of a key parameter that affects returns to labor mobility, namely, the lower support z^{min} of the productivity distribution. We describe that fragility by conducting a quantitative sensitivity analysis with respect to the parameter z^{min} after first describing MP's calibration strategy.

MP (1999, pp. 256-257) describe their calibration strategy as follows:

> "The policy parameters are chosen to reflect the US case. All other structural parameters, except for the value of leisure b and minimum match product [z^{min}] which are chosen so that the steady state unemployment rate and the average duration of an unemployment spell match the average experience in the United States over the past twenty years, are similar to those assumed and justified in Mortensen (1994) and Millard and Mortensen (1997)."

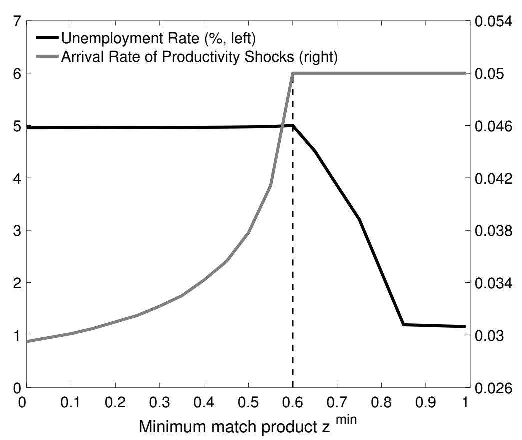
That calibration of values of leisure and z^{min} is confirmation by Millard and Mortensen (1997, p. 555) who say:

> "...two parameters for which there is no direct evidence, the forgone value of leisure b and a measure of dispersion in the idiosyncratic shock denoted as [z^{min}], are chosen to match the average duration of unemployment and incidence of unemployment experienced over the 1983-92 period."

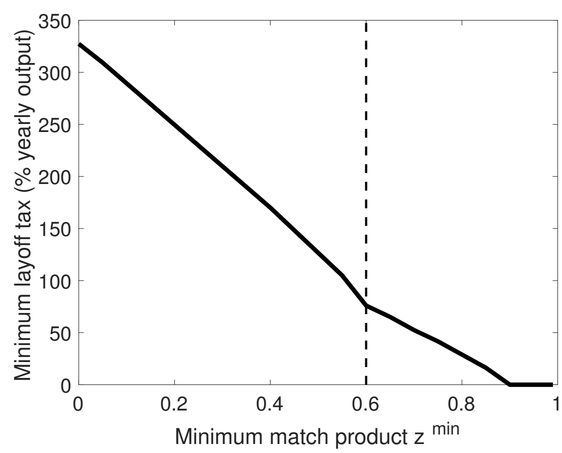
For a given steady-state unemployment rate, calibrations of the average duration of an unemployment spell and the incidence of unemployment are two sides of the same coin. Below, we calibrate to target the incidence of unemployment. However, our most important move is to put another of MP's parameters for which we have no direct evidence on the table, namely, the arrival rate γ^s of productivity shocks.

We use the laissez-faire version ($\phi = \Omega = 0$) of the benchmark model with the MP productivity process in the third panel of Table 4 to explain this important tradeoff associated with the choice of a pair (z^{min}, γ^s). Recall that the economy is parameterized to have $z^{min} = 0.6$ and a productivity switch probability $\gamma^s = 0.005$ in the semi-quarterly model period (which corresponds to MP's quarterly probability 0.1 in Table 3). Now, in accordance with MP's target of a particular incidence of unemployment (or, on the flip side, a particular average duration of an unemployment spell), we 'freeze' the laissez-faire economy's quarterly separation rate of 6.77 percent. Specifically, for each value of $z^{\min} \leq 0.6$, we find an associated value of γ^s that implies an unchanged quarterly separation rate. The lighter curve in Figure 9a traces out the pairs of (z^{min}, γ^s) that attain the targeted quarterly separation rate of 6.77 percent. In our 'normal' parameter range, there is a positive relationship between z^{min} and γ^s, because a higher z^{min} means smaller dispersion of productivities and therefore fewer shocks that call forth endogenous quits so the exogenous arrival rate of shocks γ^s has to be raised to keep the separation rate unchanged. The darker line shows that the laissez-faire unemployment rate remains constant at 5 percent throughout these calculations for $z^{\min} \leq 0.6$.

Figure 9: Calibration of benchmark model with MP productivity z^{min}



(a) Arrival rate of productivity shocks, γ^s



(b) Minimum layoff tax to shut down quits

We can also extend these calculations for $z^{\min} > 0.6$ (not shown); but after 0.64 no γ^s can be found to generate as high a quarterly separation rate as 6.77 percent. To see why, notice that the lighter curve in Figure 9a becomes ever steeper as it approaches $z^{\min} = 0.6$ from below. Evidently, this arithmetic must eventually come to a stop, since it would be impossible to maintain *any* endogenous separations as the parameter z^{min} approaches the upper support of 1 where the productivity distribution would become degenerate as a single mass point. Instead of depicting the breakdown of our algorithm, we simply freeze all the parameters of the economy at $z^{min} = 0.6$, except for the parameter itself as we compute equilibria for higher values of z^{min}. As depicted in Figure 9a for $z^{\min} > 0.6$ and a constant productivity switch probability $\gamma^s = 0.05$, the unemployment starts falling until all endogenous separations come to a halt and the unemployment curve becomes horizontal to reflect exogenous rates of retirement $\rho^r = 0.0031$ and breakups $\rho^x = 0.005$.

Figure 9b refers to the welfare-state configuration of the model with replacement rate $\phi = 0.7$ in the third panel of Table 4. The figure depicts the minimum layoff tax required to shut down all endogenous separations measured in terms of an average worker's annual output in the laissez-faire economy. As discussed in section 3.1, the welfare state needs a higher layoff tax to shut down than does the laissez-faire economy. That is also true when comparing the far-right flattening of the layoff-tax curve at zero for the welfare state in Figure 9b and the flattening of the laissez-faire unemployment curve in Figure 9a (which is trivially associated with no layoff tax required to shut down endogenous separations because they have already come to a halt). This tiny slice of the z^{min}-range where endogenous separations have shut down in the laissez-faire economy and are barely present in the welfare state would be the counterpart to the DHHR model, as discussed in section 3.1. In contrast, the LS model in that section, i.e., the benchmark model with the LS productivity process, requires a minimum layoff tax of circa 180 percent of a worker's annual output so that the counterpart in Figure 9b would be the benchmark model with a MP productivity process with $z^{\min}$ of around 0.35.

A final take-away from Figure 9 is that MP unnecessarily constrained themselves by postulating a quarterly productivity switch probability 0.1 in Table 3. That caused MP to back themselves into a treacherous region of the parameter space in which further small increases in $z^{\min}$ would have rendered MP's calibration targets unattainable: the range of the uniform distribution would become too small to generate big enough returns to labor mobility.[16]

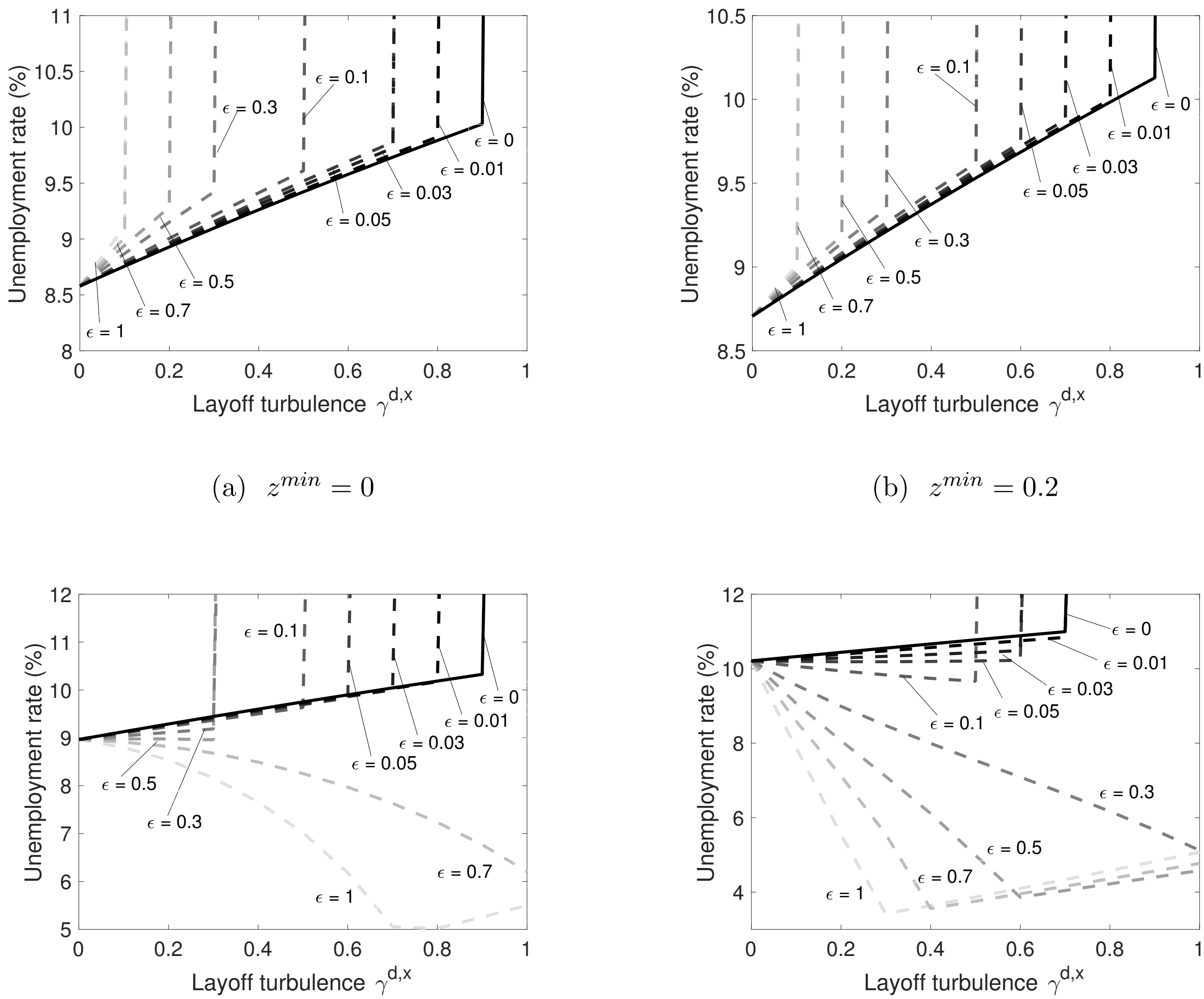
5.3 Turbulence under MP productivity process

Figure 10 depicts how unemployment responds to turbulence in four of the calibrated economies from Figure 9, indexed by $z^{min} \in \{0, 0.2, 0.4, 0.6\}$. The two top panels show robust positive

[16]In personal communications with us, Stephen Millard described how he and Dale Mortensen used evidence on firing costs that they gleaned from data on the experience rating feature of the U.S. unemployment insurance system to calibrate parameters z^{min}, γ^s and the value of leisure to match targets for the unemployment rate (6.5%), unemployment incidence (7%), and the elasticity of unemployment incidence with respect to firms' firing cost (0.09). They calibrated these three parameters by solving three simultaneous equations, conditional on the other parameters. (See also Mortensen (1994, p. 203)). Evidently, the resulting quarterly value $\gamma^s = 0.1$ was imported to MP (1999, pp. 256-257) who calibrated the value of leisure and z^{min} to the steady state unemployment rate and the average duration of an unemployment spell.

turbulence-unemployment relationships for any combination of layoff and quit turbulence.

Figure 10: Turbulence with MP productivity z^{min}



(a) $z^{min} = 0$

(b) $z^{min} = 0.2$

(c) $z^{min} = 0.4$

(d) $z^{min} = 0.6$

A new feature is the possibility of a spike indicating a 'meltdown' that occurs when the unemployment rate soars to a level of 55-60 percent (outside of the graphs). The following forces cause the meltdown. Under MP's assumption that all new jobs start with a productivity equal to the upper support of the distribution, a reservation productivity can take only one of two possible values: either the upper support of the distribution is acceptable to a worker-vacancy encounter or it is not. This creates a possible a 'tipping point' at which a change in turbulence moves the economy *from* an equilibrium in which all worker-vacancy encounters result in matches *to* an equilibrium in which there is no Nash-bargaining solution for some worker-vacancy encounters. This happens at the meltdowns in Figure 10: firms cannot afford to pay a wage to low-skilled workers with high benefits that is high enough to compensate them for surrendering their high benefits. When turbulence reaches that tipping point, the stochastic steady state becomes one in which skill loss leads to an absorbing state of unemployment until retirement – a 'turbo-charged' positive turbulence-unemployment relationship.

In the preceding subsection, we mapped the LS model, i.e., the benchmark model with the LS productivity process, into a corresponding economy with the MP productivity process in Figure 9b. We argued that the corresponding economy would be one with $z^{min} = 0.35$. Interestingly, the turbulence outcomes in Figure 10c with $z^{min} = 0.4$ resemble those of Figure 4a for the benchmark model with the LS productivity process. In particular, only high levels of quit turbulence can cause a negative turbulence-unemployment relationship.

Regarding the turbulence outcomes in Figure 10d with $z^{min} = 0.6$, there is a close resemblence to that present in our earlier Figure 5. The latter figure refers to our experiment that imports the DHHR productivity process into the benchmark model and finds returns to labor mobility that are suppressed but not so low as in the DHHR model. Since Figure 5 can be thought of as an intermediate step in moving from high to very low returns to mobility, the same can be said about Figure 10d with $z^{min} = 0.6$. Since the latter model is also our benchmark model with the MP productivity process that reproduces MP's unemployment outcomes in Table 4, it becomes another way of expressing what we said earlier about MP approaching a troublesome region of the parameter space.

6 Returns to labor mobility in AV

To study effects of firing costs and severance payments in an incomplete markets setting in which rigid wages don't depend on individual firms' states and risk-averse agents self-insure against income risk, Alvarez and Veracierto (2001), AV, formulate a search-island model in the tradition of framework of Lucas and Prescott (1974).[17] A state-independent wage and an incentive to self-insure are features that are absent from the benchmark model in which workers are risk neutral and wages are determined in Nash bargaining between a worker and a firm. For our present purposes, the object of the Alvarez-Veracierto model that interests us is the stochastic process governing idiosyncratic productivities that, intermediated through a production function, determine workers' outputs. AV calibrate a productivity distribution that they coax from establishment data on job creation and destruction (Davis and Haltiwanger, 1990) cast within a model in which outcomes are shaped by a neo-classical production function.

[17] Because they calibrate their model to Davis and Haltiwanger's (1990) establishment data, AV use the term "establishment" instead of "firm".

An individual firm's output y_t at time t is given by the production function

$$y_t = x_t \, k_t^{\xi} \, n_t^{\psi} \, , \tag{26}$$

where $\xi > 0$, $\psi > 0$, $\xi + \psi < 1$, k_t is capital, n_t is labor, and x_t is an idiosyncratic productivity shock. The idiosyncratic shock x_t can take one of three values $\{0, x^{low}, x^{high}\}$ and follows a first-order Markov process with a transition probability matrix Q. Zero productivity is an absorbing state that indicates death of a firm.

The transition probability matrix Q takes the following form:

$$Q = \begin{bmatrix} 1 & 0 & 0 \\ \eta & \omega(1-\eta) & (1-\omega)(1-\eta) \\ \eta & (1-\omega)(1-\eta) & \omega(1-\eta) \end{bmatrix} , \tag{27}$$

where $\eta \in (0, 1)$ is the probability of a firm's death and, conditional on surviving, $\omega \in (0, 1)$ is the probability that a firm's productivity is unchanged from last period. The transition probability matrix Q in (27) treats low and high productivity shocks symmetrically. In addition, initial productivities drawn by new firms have equal probabilities of being low and high. Under these assumptions, there are as many firms with low productivity as with high productivity in a stochastic steady state.

Table 6 lists parts of AV's parameterization that are central to us. The production function is calibrated in a standard way to match commonly used targets: AV calibrate the capital share parameter ξ to match the U.S. capital-output ratio and the labor share parameter ψ to replicate a labor share in national income of 0.64. For a semi-quarterly model period and normalization $x_1 = 1$, AV (2001, p. 488)

> "select the parameters [η], ω and [x_2] to reproduce observations on job creation and job destruction reported by Davis and Haltiwanger (1990): the average job creation and job destruction rates due to births and deaths are both about 0.73 percent a quarter, the average job creation and job destruction rates due to continuing establishments are about 4.81 percent a quarter, and the annual persistence of both job creation and destruction is about 75 percent. We obtained these observations by selecting [x_2] = 2.12, [η]= 0.0037, and ω = 0.973."[18]

Note that AV's empirical targets for quarterly job churning sum to 5.5 percent – 0.73 percent due to births and deaths of establishments and 4.81 percent from job creation and job destruction due to continuing establishments. This total rate of 5.5 percent lines up well

[18]We have corrected AV's (2001, p. 488) erroneous reference to "[η] = 0.037" with the correct number 0.0037, as reported in Table 1 of AV's 1998 working paper (Federal Reserve Bank of Chicago, WP 98-2).

Table 6: AV's parameter values (central to our study)

Parameter	Definition	Value
Technology		
ξ	capital share	0.19
ψ	labor share	0.58
Productivity		
x_2	high productivity	2.12
ω	persistence of productivity	0.973
η	death of firm	0.0037

with outcomes in the benchmark model with the LS productivity process and without a layoff tax in the rightmost panel of Figure 2, in which the quarterly separation rate is around 5.7 percent. Also, there is a quantitatively close overlap between the empirical 0.73 percent a quarter attributed to establishment turnover, modelled as an exogenous firm failure rate by AV (i.e., twice the semi-quarterly rate $\eta = 0.0037$ in Table 6), and the exogenous breakup/layoff rate of 1 percent assumed in the benchmark model (i.e., twice the semi-quarterly rate $\rho^x = 0.005$ in Table 1). It remains for us to describe how to map the AV productivity process pertaining to production functions with both capital and labor into our matching framework and the productivities of one-worker firms with no physical capital.

6.1 A simplified AV model

We simplify AV's benchmark economy by assuming an endowment of perpetual firms, and by eliminating a minor firing tax. First, instead of AV's costly creation of new establishments, suppose that the economy is endowed with a fixed measure of firms equal to the steady-state measure in AV's benchmark economy. And whenever a firm dies with probability η, it is replaced by a new firm as in AV's steady state, but now without any cost of creation. We retain AV's assumption that a banking sector owns both the establishments and the capital that they rent. Second, we eliminate a minor firing tax in AV's (2001, p. 487) benchmark economy that represents employers' experience-rated tax to finance the unemployment benefit system, motivated by AV's argument that "these taxes work approximately as firing taxes". Instead, the government could marginally increase the payroll tax by the annuitized expected value of that minor firing tax.[19]

With the firm creation cost and the firing tax gone, a firm's problem is purely static. A firm

[19] According to AV's 1998 working paper (Federal Reserve Bank of Chicago, WP 98-2), the firing tax is equal to only 30 percent of the semi-quarterly before-payroll-tax wage rate.

maximizes profits renting enough capital and labor in spot markets to equate their marginal products to the rental rate on capital r and the before-payroll-tax wage $w^\star$, respectively. In a steady state, there are only two types of firms: firms with low (high) productivity, of which each one rents k_1 (k_2) units of capital and hires n_1 (n_2) workers. In this stationary equilibrium, we can switch from a time subscript on variables to a state subscript: state 1 stands for low productivity, $x_1 = x^{low}$, and state 2 for high productivity, $x_2 = x^{high}$.

In an equilibrium, the marginal product of labor in both types of firms equals the wage $w^\star$,

$$w^\star = \psi\, x_1\, k_1^\xi\, n_1^{\psi-1} = \psi\, x_2\, k_2^\xi\, n_2^{\psi-1}\,. \tag{28}$$

After dividing both sides of the last equality by $\psi\, x_1\, k_1^\xi\, n_1^\psi\, n_2^{-1}$, we have

$$\frac{n_2}{n_1} = \frac{x_2}{x_1}\left(\frac{k_2}{k_1}\right)^\xi \left(\frac{n_2}{n_1}\right)^\psi . \tag{29}$$

Likewise, the marginal product of capital equals the rental rate r,

$$r = \xi\, x_1\, k_1^{\xi-1}\, n_1^\psi = \xi\, x_2\, k_2^{\xi-1}\, n_2^\psi\,. \tag{30}$$

After dividing both sides of the last equality by $\xi\, x_1\, k_1^\xi\, n_1^\psi\, k_2^{-1}$, we have

$$\frac{k_2}{k_1} = \frac{x_2}{x_1}\left(\frac{k_2}{k_1}\right)^\xi \left(\frac{n_2}{n_1}\right)^\psi . \tag{31}$$

Since the right-hand sides of expressions (29) and (31) are the same, the capital-labor ratio is the same across all firms,

$$\frac{n_2}{n_1} = \frac{k_2}{k_1} \qquad \Rightarrow \qquad \frac{k_1}{n_1} = \frac{k_2}{n_2}\,. \tag{32}$$

By substituting (32) into expression (29), the ratio of labor employed by the two types of firms is

$$\frac{n_2}{n_1} = \frac{x_2}{x_1}\left(\frac{n_2}{n_1}\right)^\xi \left(\frac{n_2}{n_1}\right)^\psi \qquad \Rightarrow \qquad \frac{n_2}{n_1} = \left(\frac{x_2}{x_1}\right)^{\frac{1}{1-\xi-\psi}} . \tag{33}$$

When using AV's parameterization in Table 6 to evaluate expression (33), a low-productivity firm employs only 3.81 percent as many workers as a high-productivity firm does. Furthermore, since there are equal numbers of the two types of firms, it follows that high-productivity firms account for more than 96 percent of aggregate employment.

6.2 Mapping AV's productivity process into benchmark model

We use two steps to map AV's productivity process into the benchmark model. First, for our simplified AV model in the preceding section, we construct a hypothetical wage schedule of a firm that experiences a switch from high to low productivity, but offers all its workers to remain in the firm at a schedule of different pay. Second, we re-interpret that hypothetical wage schedule as a probability distribution of productivities in our matching framework with one-worker firms.

For the first step, consider a high-productivity firm that has just experienced a shock of low productivity, but instead of reducing its employment by $n_2 - n_1$ workers, the firm randomly orders its current employees and offers the following wage schedule. The first n_1 workers are offered the wage rate $w^\star$, i.e., the market-determined wage rate that all firms pay to their workers and n_1 is the employment level of other low-productivity firms. Then, under a pledge to keep the capital-labor ratio unchanged, the firm offers each successive worker in the randomly arranged order a wage equal to her marginal product. Thus, the wage offered to the worker in position $n \in (n_1, n_2]$ is given by

$$\begin{aligned}
\psi\, x_1\, k^\xi\, n^{\psi-1} &= \psi\, x_1\, k^\xi\, n^{\psi-1} \frac{w^\star}{\psi\, x_2\, k_2^\xi\, n_2^{\psi-1}} = \frac{x_1 \left(\frac{k}{n}\, n\right)^\xi n^{\psi-1}}{x_2 \left(\frac{k_2}{n_2}\, n_2\right)^\xi n_2^{\psi-1}}\, w^\star \\
&= \frac{x_1}{x_2}\left(\frac{n}{n_2}\right)^{-(1-\xi-\psi)} w^\star \;\equiv\; \Gamma_{w^\star}\!\left(\frac{n}{n_2}\right) \qquad \text{for } \frac{n}{n_2} \in \left(\frac{n_1}{n_2}, 1\right], \qquad (34)
\end{aligned}$$

where the first equality multiplies and divides by the same quantity $w^\star$ while in the denominator imposing that $w^\star$ equals the marginal product of labor in a high-productivity firm, as given by expression (28), and the third equality uses the firm's pledge to keep the capital-labor ratio unchanged; hence, in the numerator and denominator the capital-labor ratio cancels.

The search frictions that workers face in a search-island model would make some workers in our simplified AV model choose to accept wage offers below $w^\star$. But under AV's parameterization, the vast majority would decline such offers and instead enter the pool of unemployed. However, for our purposes, it is useful to proceed as if all workers choose to remain with the firm. Since the argument of wage schedule $\Gamma_{w^\star}(n/n_2)$ is employment position n relative to the employment level of a high-productivity firm, the inverse function $\Gamma_{w^\star}^{-1}(w)$ gives the fraction of workers earning a wage greater than or equal to w and hence, the fraction of workers earning less than or equal to w is given by

$$F_{w^\star}(w) = 1 - \Gamma_{w^\star}^{-1}(w) = 1 - \left[\frac{x_1 w^\star}{x_2 w}\right]^{\frac{1}{1-\xi-\psi}} \qquad \text{for } = w \in \left[\frac{x_1 w^\star}{x_2},\, w^\star\right), \qquad (35)$$

and the fraction of workers at the mass point $w = w^\star$ is equal to

$$1 - \lim_{w \to w^\star} F_{w^\star}(w) = \Gamma^{-1}_{w^\star}(w^\star) = \left[\frac{x_1}{x_2}\right]^{\frac{1}{1-\xi-\psi}} \tag{36}$$

which is indeed the same as the equilibrium value of n_1/n_2 in expression (33).

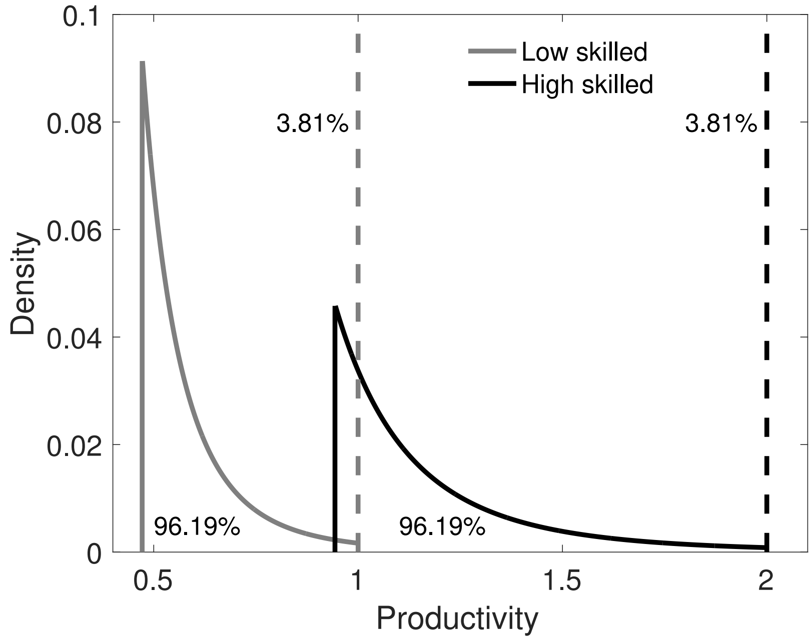
In the second step of our mapping of AV into the benchmark model, we re-interpret the shocks of AV as follows. AV's probability η that a firm dies becomes our probability ρ^x of an exogenous breakup. AV's probability $1-\omega$ that a firm receives a productivity shock becomes our probability γ^s that a productivity switch hits a continuing firm-worker match. At such a switch, a new productivity z is now drawn from a skill-specific distribution $F_{z_i^{max}}(z)$ where $i = l$ and $i = h$ for a low-skilled and a high-skilled worker, respectively, with cumulative density

$$F_{z_i^{max}}(z) = 1 - \Gamma^{-1}_{z_i^{max}}(z) = 1 - \left[\frac{x_1\, z_i^{max}}{x_2\, z}\right]^{\frac{1}{1-\xi-\psi}} \qquad \text{for } = z \in \left[\frac{x_1\, z_i^{max}}{x_2},\, z_i^{max}\right), \tag{37}$$

and the probability of mass point $z = z_i^{max}$ is given by expression (36). We take AV's variable $w^\star$ as the upper bound z_i^{max} of our skill-specific productivity distribution. It is a rather direct analogue to the above hypothetical wage schedule in the simplified AV model, but instead of workers being randomly assigned along a wage offer schedule, continuing firm-worker matches in the benchmark model draw productivities from a corresponding distribution. In accordance with AV and similar to MP in the preceding section, the productivity of a newly formed firm-worker match is equal to the upper support of the productivity distribution.

Figure 11 depicts the densities of our two skill-specific productivity distributions when blending AV's parameterization in Table 6 with the assumption of the benchmark model that a low-skilled worker has half the earnings potential of a high-skilled worker, $z_l^{max} = 1$ and $z_h^{max} = 2$. The shape of a density reflects the concavity of AV's production function. In particular, since we imposed a constant capital-labor ratio in the employment perturbations away from an efficient level of operation, the concavity of a firm's output with respect to employment arises from AV's assumption of decreasing returns to scale. The lowest productivity of a distribution in Figure 11 reflects an excessively high employment level of a firm that has not shed its labor force after switching from high to low productivity. Hence, the excessively high employment is far up on a flattening concave production function where a rather small increase in the marginal product of labor would be associated with a relatively long journey down the production surface to significantly lower employment levels that explains the high densities at those low productivities. The reasoning is the opposite for productivities just below the efficient employment level, where the steeper curvature of the concave production function means that a small increase in the marginal product of labor does not have much of an associated change

Figure 11: AV PRODUCTIVITY DISTRIBUTIONS



in employment, providing the low densities at high productivities just below the efficient level. The mass point at the upper support reflects that all workers employed at that efficient level are paid the marginal product of labor evaluated at that efficient employment level.

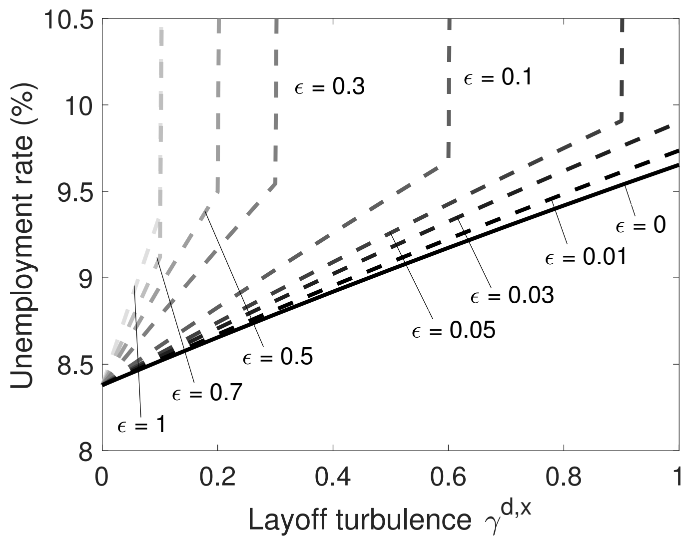
6.3 Turbulence under AV productivity process

As in section 5.3, we import the AV productivity process into the benchmark model to study how unemployment respond to turbulence. Thus, we adopt the AV productivity process as parameterized in Table 6 with the adapted productivity distribution in expression (37) while keeping the rest of the parameterization of the benchmark model in Table 1, except for the matching efficiency A that we calibrate to target a laissez-faire unemployment rate of 5 percent in tranquil times.

The turbulence outcomes under the AV productivity process in Figure 12 resemble those under the versions of the MP process in the top two panels of Figure 10 and indicate a strong positive relationship between unemployment and turbulence. Actually, the relationship is even stronger under the AV productivity process given the functional form of the AV probability distribution with densities depicted in Figure 11. That functional form reflects AV's underlying growth model as mirrored in its neo-classical production function. The theoretical structure makes it difficult to imagine how any plausibly parameterized quit turbulence could ever suppress the strong forces for reallocation of workers across establishments that are present in the

AV model.

Figure 12: TURBULENCE WITH AV PRODUCTIVITY



The establishment data on firm and worker turnover (Davis and Haltiwanger, 1990) that AV use to calibrate their model, and data sets from other countries, provide overwhelming empirical evidence of extensive reallocations across diverse market economies with different types of government policies. Our present study of the consequences of alternative labor productivity processes in macro-labor models conveys a message consistent with that evidence: explaining observations on firm turnover, labor mobility, and prevalent government policies that aim to arrest firm-worker separations requires theoretical constructs calibrated with ample returns to labor mobility. Quantitative models that have meager returns to labor mobility cannot explain these observations.

7 Concluding remarks

This paper contributes a macro-labor economics variation on a theme of particle physicist Steven Weinberg (2018, p. 197):

> "... often the most important constraint on a new theory is ... that it should agree with the whole body of past observations, as crystallized in former theories. ... New theories of course do not agree entirely with any previous theory – otherwise they would not be new – but they must not throw out all the success of former theories. This sort of thing makes the work of the theorist far more conservative than is often thought.

> The wonderful thing is that the need to preserve the successes of the past is not only a constraint, but also a guide."

For us here, "successes of the past" are the many macro-labor models that have fit data on labor market flows and generated plausible responses of unemployment rates to government policies like unemployment insurance and layoff taxes. Revisiting some of those successes by mapping productivity processes from celebrated studies into our benchmark model has taught us more about the determinants of their returns to labor mobility. In particular, models like AV's that include firm size dynamics and are calibrated to fit them are likely to have very robust returns to labor mobility when shocks to productivity are intermediated through neoclassical production functions. But other macro-labor models that rely solely on unemployment statistics to calibrate per-worker productivity processes can encounter serious issues about robustness of returns to labor mobility. Thus, we discovered a previously undetected fragility in MP's calibration that emerges in the form of a ridge traced out by two key parameters that can generate the same targeted unemployment statistic although they have very different implications for returns to labor mobility. MP seemed not to notice that their calibration resides at the end of that ridge, close to a region where returns to labor mobility are very sensitive to perturbations of those parameters. MP focused on employment effects of layoff taxes, so equilibrium outcomes would have made them acutely aware of this issue if their calibration had wandered into the region with extremely low returns to mobility. That would probably have prompted them to explore their parameter space further, since market economies, even those with heavy-handed government interventions, are characterized by substantial labor reallocation. Starting from that widespread professional consensus about observed labor mobility and its implications for returns to labor mobility, we have demonstrated that a turbulence-theoretic explanation of trans-Atlantic unemployment experiences survives the addition of well calibrated quit turbulence.

Returns to labor mobility have too often slipped under the radar and escaped the attention they deserve as conduits of important forces in macro-labor models. The fact that returns to labor mobility are essential contributors to various phenomena brings informative cross-phenomenon restrictions that can guide calibrations of productivity processes. Exploiting such restrictions adheres to advice offered by Lucas (1980, pp. 696-697):

> "... we are interested in models because we believe they may help us to understand matters about which we are currently ignorant, we need to test them as useful imitations of reality by subjecting them to shocks for which we are fairly certain how actual economies, or parts of economies, would react. The more dimensions on which the model mimics the answers actual economies give to simple questions, the more we trust its answers to harder questions."

In our application, Lucas's relatively "simple question" is about cross-country observations on how layoff costs have seemed to suppress labor reallocation, while the "harder question" about which much less is known concerns unemployment effects of quit turbulence. We hope that our findings will promote further studies of the role that returns to labor mobility play in macro-labor models.

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