A New Keynesian ‘plucking’ model of unemployment and inflation

PRELIMINARY AND INCOMPLETE

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Abstract

We construct a New Keynesian model with search-and-matching frictions in the labour market that can generate the nonlinear 'plucking' dynamics of unemployment in the data: unemployment tends to spike upwards and then slowly decline. The model features endogenous layoffs, a 'slippery' job ladder, downward nominal wage rigidity, and convex recruiting costs. It generates both the 'deepness' and 'steepness' asymmetries in unemployment dynamics, and broadly matches the response of labour-market flows in a downturn. The model endogeneously generates a Phillips curve relationship that is strongly nonlinear and state-dependent, and a short-run non-accelerating rate of unemployment (NAIRU) that fluctuates asymmetrically over the business cycle. We also show that cyclical properties (e.g. shock volatility, nominal rigidities, policy regime) can have a significant effect on the long-run NAIRU via agents' precautionary response to future uncertainty.

JEL Classification Numbers:

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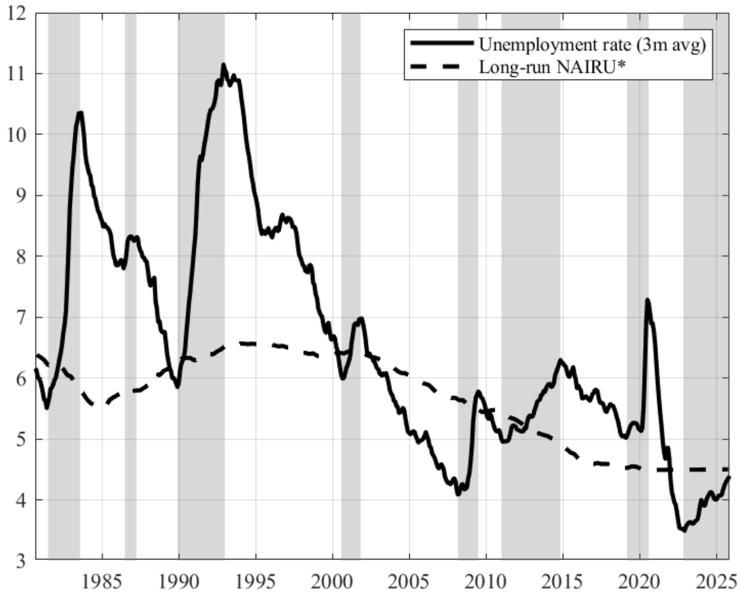
Figure 1: Unemployment rate in Australia



*Long-run NAIRU estimate from Ballantyne and Cusbert (2025).

1. Introduction

The unemployment rate in the data has strongly nonlinear dynamic (Figure 1). It spikes sharply in occasional downturns, then declines slowly but persistently in recoveries.[1] It is right-skewed in both levels (i.e. asymmetric 'deepness') and in changes (i.e. asymmetric 'steepness') (Sichel 1993). Gross flows between unemployment and employment display similar nonlinearities. Standard search-and-matching models of the labour market struggle to generate these nonlinearities in unemployment and labour-market flows (Ferraro 2023).

If this asymmetric pattern stems from frictions within the labour market, what implication do those frictions have for the relationship between inflation and unemployment? Research using nonlinear structural models to explore the asymmetric dynamics in the labour market tend to abstract from price frictions and inflation dynamics (e.g. Dupraz, Nakamura and Steinsson 2025; Ferraro 2018; Petrosky-Nadeau, Zhang and Kuehn 2018), while in the New Keynesian literature, the usual approach of linearising equilibrium conditions excludes these nonlinear dynamics by assumption. The 2020s inflation surge has reignited research into the nonlinearity of the Phillips curve, and the extent to which this nonlinearity stems from frictions within the labour market (e.g. Benigno and Eggertsson 2023). But this literature tends not to model the labour market in as much detail.

In this paper, we explore the extent to which a detailed search-and-matching model of the labour market with pricing frictions can match the nonlinear dynamics in the labour market. We then use the model to examine the implications of these nonlinearities for the Phillips curve relationship and the non-accelerating rate of unemployment (NAIRU).

1 Friedman (1964) uses the 'plucking' description for the asymmetric way in which output seems to be occasionally 'plucked' below trend, before recovering back to trend.

We start with a general-equilibrium search-and-matching model similar to Bloesch, Lee and Weber (2024), in which firms post wages and vacancies and set prices (subject to nominal rigidities and recruiting costs), and workers search (while unemployed and on the job) and decide whether to accept and quit jobs. Policy steers aggregate demand to balance inflation and unemployment targets. We extend this model to include endogenous layoffs, downward nominal wage rigidity, and a 'slippery' job ladder (drawing on Dupraz *et al* (2025)).[2] We find that these features - together with convex recruiting costs - are collectively key to achieving both the asymmetric spikes in unemployment when shocks occur and the slow speed in the subsequent recovery. The model is sufficiently detailed to broadly match the dynamics of unemployment and gross flows, but tractable enough that we can obtain the global nonlinear solution with rational expectations and aggregate uncertainty. This is important because agents' precautionary response to future uncertainty is a significant determinant of outcomes, especially the long-run NAIRU.

We show that the model can generate substantial asymmetry in both 'deepness' and 'steepness' (comparable to or greater than in the data). The response of unemployment, job-finding, and separations after a stylised negative demand shock broadly matches the response of these variables in downturns over the past 50 years. Aggregate demand shocks have an especially asymmetric effect, because the effect on inflation amplifies the effect of the downward nominal wage rigidity. When supply shocks occur, the inflation response somewhat eases the downward nominal wage constraint.

The model endogenously generates a Phillips curve relationship that is strongly nonlinear and state-dependent. Conditional on some initial state of the economy, the Phillips curve is much steeper for low rates of unemployment. When the initial unemployment rate is higher, the Phillips curve shifts to the right, and when the initial level of real wages is higher, it shifts upwards.

We can also use the model to simulate a 'short-run NAIRU', which is the unemployment rate consistent with eliminating inflationary pressure from the labour market at some cyclical horizon (e.g. 1-2 years). This short-run NAIRU varies asymmetrically with the state of the economy. It tends to rise when unemployment is high, but also when unemployment has fallen rapidly (because real wages increase).

Finally, we can use the 'stochastic steady state' of the model to explore the determinants of the long-run NAIRU, i.e. the unemployment rate consistent with stable inflation in the absence of shocks (but where agents still expect that shocks may occur in the future). We find that when firms account for the interaction between aggregate risk and asymmetric wage adjustment costs in their wage-setting decisions, it generates a trade-off between unemployment variance and steady-state unemployment. For example, if policy places greater weight on reducing the gap between unemployment and the long-run NAIRU (instead of the gap between inflation and target), it tends to *increase* the long-run NAIRU. This is because by mitigating fluctuations in labour demand, policy reduces the risk of hitting downward nominal wage rigidities. Firms are then more willing to set higher real wages in steady state, which reduces the optimal amount of employment in steady state.

The remainder of this introduction discusses the literature. Section 2 outlines the model. Section 3 evaluates the extent to which it can match the nonlinear dynamics in labour-market data. Section 4 considers the implications for the Phillips curve and NAIRU.

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2 By 'slippery' job ladder, we mean that workers recently hired out of unemployed are much more likely to be laid off.

Literature review. The cyclical asymmetries in unemployment are established empirically by e.g. Sichel (1993), McKay and Reis (2008), and Dupraz *et al* (2025). Ferraro (2023) analyses the ability of the baseline Diamond-Mortensen-Pissarides (DMP) model to produce these asymmetries, and finds that it cannot generate the 'steepness' asymmetry (i.e. right-skewness in unemployment changes). Petrosky-Nadeau *et al* (2018) finds that the DMP model can generate the 'deepness' asymmetry given large enough shocks.

Dupraz *et al* (2025) and Ferraro (2018) propose search-and-matching models that can generate sharp spikes and slow declines in unemployment. We take several features from Dupraz *et al* (2025), including downward nominal wage rigidity and a 'slippery' job ladder. Pizzinelli, Theodoridis and Zanetti (2020) explore the state-dependence of unemployment fluctuations in a model with endogenous layoffs and on-the-job search.[3] Adjemian, Karamé and Langot (2021) estimate a nonlinear model with endogenous separations, downward wage rigidity, worker heterogeneity and segmented markets, and show that it can generate similar asymmetries in unemployment, hiring, and separations to the data.

Our definition of a 'short-run NAIRU' is similar to the concept discussed by Hall and Kudlyak (n.d.), who argue that the natural rate of unemployment may vary cyclically and track the actual unemployment rate during recoveries. Hall and Kudlyak (2022) discusses the ability of DMP-style models to generate the slow persistent recovery in unemployment that occurs after recessions. Fujita and Ramey (2007) show that adding vacancy adjustment costs to a DMP model can produce a more sluggish response for vacancies and hiring after a downturn, slowing down the recovery in unemployment. Mercan, Schoefer and Sedláček (2024) suggest a congestion mechanism, whereby new hires and incumbent workers are imperfect substitutes in production, which also propagates unemployment after a shock.

This literature above generally abstracts from price rigidities and inflation dynamics. There is a substantial literature incorporating labour-market frictions into New Keynesian models (see e.g. Blanchard and Galí 2010). Recent examples include Moscarini and Postel-Vinay (2023), Faccini and Melosi (2025), and Bloesch *et al* (2024). These papers focus on the role of on-the-job search and wage competition between firms in inflation dynamics. We adopt a similar model for wage setting, drawing on the tractable formulation in Bloesch *et al* (2024). But these papers use linear approximations.

The literature on downward nominal wage rigidity explores the extent to which it generates a nonlinear Phillips curve and asymmetric cyclical dynamics (see e.g. Kim and Ruge-Murcia 2009; Abbritti and Fahr 2013; Daly and Hobijn 2014; Benigno and Antonio Ricci 2011; Schmitt-Grohé and Uribe 2022; Benigno and Eggertsson 2023; Benigno and Eggertsson 2024). Lepetit (2020) also constructs a New Keynesian model with asymmetric unemployment dynamics, although the asymmetry stems from the convex relationship between the job-finding rate and unemployment. This literature does not model the labour market in as much detail (e.g. endogenous layoffs, on-the-job search, job ladder) and does not seek to match the 'plucking' property in unemployment to the same extent.

3 Fujita and Ramey (2012) also analyse versions of the DMP model with endogenous separations and on-the-job search, but their focus is not on asymmetries in unemployment rate dynamics

2. Model

The model consists of firms, workers, and a policy rule. We start by outlining the firms' problem and optimal choices. Firms' optimal decision-making drives most of the model's mechanics. We then discuss workers and the policy regime, which are modelled more simply. 5 contains a full list of equilibrium conditions, as well as details of the calibration and solution method.

2.1 Firms

Firms make decisions around hiring, separations, and price- and wage-setting.

Hiring: Firms choose how many vacancies to post, V_t^i. These vacancies generate $M_t^i = q_t V_t^i$ matches, where q_t is determined by a matching function and depends on aggregate matching efficiency and labour market tightness. A proportion $1-\phi_t^E$ of these matches are unemployed searchers (where ϕ_t^E is the share of unemployed searchers in total searchers, weighted by search intensity).

Firms must screen matches. Then the individual productivities of employed matches are revealed. Firms make offers to those with productivities above some threshold $\underline{x}_t^i$, which is $1-F_t^i$ of them (where $F_t^i = F(\underline{x}_t^i)$ and F is the CDF of the individual productivity distribution). For unemployed matches, firms have no information about their individual productivity and make offers to all of them. This feature proxies for the idea that firms may be more uncertain about the capabilities of unemployed applicants.

Matches with offers choose whether to accept them; $Ac_t^e(W_t^i)$ and employed matches and $Ac_t^u(W_t^i)$ of unemployed matches do so, where W_t^i is the real wage paid by the firm. These job-acceptance probabilities are characterised in the description of workers below.

The number of new hires is given by

$$H_t^i = \phi_t^E M_t^i (1-F_t^i) Ac_t^e(W_t^i) + (1-\phi_t^E) M_t^i Ac_t^u(W_t^i).$$

Define $H_t^{i,u} = (1-\phi_t^E) M_t^i Ac_t^u(W_t^i)$ as the number of hires from unemployment.

Recruiting costs include a per-vacancy cost and a per-match 'screening' cost:

$$C\left(V_t^i, M_t^i, \tilde{N}_{t-1}^i\right) = \kappa^v \left(\frac{V_t^i}{\tilde{N}_{t-1}^i}\right)^{\chi} V_t^i + \kappa \left(\frac{M_t^i}{\tilde{N}_{t-1}^i}\right)^{\chi} M_t^i$$

where $\tilde{N}_{t-1}$ is the number of existing employees when aggregate shocks are revealed, and is defined below. The parameter χ determines the convexity of recruiting costs.

Separations: There are two types of separation: quits and layoffs. Each period, $Q_t(W_t^i)$ of firms' existing employees quit (either to unemployment or to another job). Just as firms' hiring rate is increasing in the real wage they offer (via the job-acceptance probabilities $Ac_t^e(W_t^i)$ and $Ac_t^u(W_t^i)$), their quits rate is decreasing in the real wage by the firm. This function is characterised in the section below on workers.

Workers' probability of being laid off depends on whether they are insecurely or securely attached. Insecurely attached employees are all those who have just been hired out of unemployed in the previous period. Before aggregate shocks are revealed, some portion of new hires from unemployment, δ^u, (i.e. who were hired the previous period), draw a new productivity from distribution G. Those whose productivities are less than some threshold $\underline{x}_{t-1}^{i,m}$ are laid off, which is G_{t-1}^i of them (where $G_t^i = G(\underline{x}_{t-1}^{i,m})$ and G is the CDF of the distribution).[4] All insecurely attached employees who are not laid off then because securely attached (together with all those who have been employed for more than one period).

After aggregate shocks are revealed and quitting decisions made, δ of securely attached employees draw a new individual productivity. Firms then decide to lay off those whose productivities are less than some threshold $\underline{x}_t^i$, which is F_t^i of them (where $F_t^i = F(\underline{x}_t^i)$ and F is the CDF of the individual productivity distribution). The layoff probability for securely attached employees will be lower than for insecurely attached employees both because $\delta < \delta^u$ and the distribution F has less mass at low values than G.

The number of employees when shocks are revealed (which is a state variable for period t decisions) is

$$\tilde{N}_{t-1}^i = N_{t-1}^i - G_{t-1}^{i,u} \delta^u H_{t-1}^{i,u}$$

and the number of employees who work at the firm in period t is

$$N_t^i = H_t^i + \left(1 - Q_t(W_t^i) - (1 - Q_t(W_t^i))\delta F_t^i\right) \tilde{N}_{t-1}^i.$$

The number of 'productivity units' (i.e. employees weighted by individual productivities) when shocks are revealed and after hiring and separations decisions are made are

$$\tilde{L}_{t-1}^i = L_{t-1}^i + \delta^u H_{t-1}^{i,u} \left((1 - G_{t-1}^{i,u}) x_{t-1}^{i,a,m} - x_{t-1}^{i,a,u}\right)$$
$$L_t^i = \left(N_t^i - (1 - Q_t(W_t^i))(1-\delta)\tilde{N}_{t-1}^i - H_t^{i,u}\right) x_t^{i,a} + H_t^{i,u} x_t^{i,a,u} + (1 - Q_t(W_t^i))(1-\delta)\tilde{L}_{t-1}^i.$$

where

$$x_t^{i,a} = \frac{1}{1 - F_t^i} \int_{\underline{x}_t^i}^{x^h} x\, dF(x)$$
$$x_t^{i,a,u} = \int_0^{x^h} x\, dF^u(x)$$
$$x_t^{i,a,m} = \frac{1}{1 - G_t^i} \int_{\underline{x}_t^{i,m}}^{x^h} x\, dG(x)$$

are average individual productivities conditional on being hired and not being laid off.

Production: Firms' production function is $Y_t^i = A_t L_t^i$.

Price and wage-setting: Firms set a (real) price P_t^i subject to the demand schedule $Y_t^i = P_t^{i^{-\theta}} Y_t$ and price-adjustment costs $Y_t \Phi(\Pi_t^i)$, where $\Pi_t^i = \frac{P_t^i}{P_{t-1}^i} \Pi_t$ is nominal price growth.

4 Note on timing: These layoffs have to occur before the revelation of new shocks, otherwise the number of hires from unemployment becomes a state variable. The $t-1$ subscript reflects this timing assumption. The state variables $\tilde{N}_{t-1}$ and $\tilde{L}_{t-1}$ for period t incorporate these layoffs and productivity draws that occurred before the shocks are realised. But since these people worked last period, the layoffs are counted in this period.

Firms set a (real) wage W_t^i subject to their labour supply schedule - which is affected by W_t^i via the offer-acceptance functions $Ac_t^e(W_t^i)$ and $Ac_t^u(W_t^i)$ and the quits function $Q_t(W_t^i)$ - and wage-adjustment costs $W_t N_t \Psi(\Pi_t^{Wi})$, where $\Pi_t^{Wi} = \frac{W_t^i}{W_{t-1}^i}\Pi_t^W$ is nominal wage growth. We assume that this real wage is the same for all the firms' securely attached employees, and insecurely attached employees are paid a discounted real wage $W_t^i - \xi$.[5] For simplicity, we assume that the discount ξ is fixed.

Optimal choices:

Firms maximise

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ P_t^i Y_t^i - \Phi(\Pi_t^i) Y_t - W_t^i (N_t^i - H_t^{i,u}) - (W_t^i - \xi) H_t^{i,u} - \Psi(\Pi_t^{W^i}) W_t N_t - C\left(V_t^i, M_t^i, \tilde{N}_{t-1}^i\right) \right\}$$

subject to:

$$\begin{aligned}
Y_t^i &= P_t^{i-\theta} Y_t \\
Y_t^i &= A_t L_t^i \\
N_t^i &= H_t^i + \left(1 - Q_t(W_t^i) - (1 - Q_t(W_t^i))\delta F_t^i\right) \tilde{N}_{t-1}^i \\
\tilde{N}_t^i &= N_t^i - G_t^{i,u} \delta^u H_t^{i,u} \\
L_t^i &= \left(N_t^i - (1 - Q_t(W_t^i))(1-\delta)\tilde{N}_{t-1}^i - H_t^{i,u}\right) x_t^{i,a} + H_t^{i,u} x_t^{i,a,u} + (1 - Q_t(W_t^i))(1-\delta)\tilde{L}_{t-1}^i \\
\tilde{L}_t^i &= L_t^i + \delta^u H_t^{i,u} \left((1 - G_t^{i,u}) x_t^{i,a,m} - x_t^{i,a,u}\right) \\
H_t^i &= H_t^{i,e} + H_t^{i,u} \\
H_t^{i,e} &= \phi_t^E M_t^i (1 - F_t^i) Ac_t^e(W_t^i) \\
H_t^{i,u} &= (1 - \phi_t^E) M_t^i Ac_t^u(W_t^i) \\
M_t^i &= q_t V_t^i.
\end{aligned}$$

We assume a symmetric equilibrium and drop the i superscripts for simpler notation.

$\mathbf{N_t}$, $\mathbf{L_t}$, $\mathbf{\tilde{N}_t}$, $\mathbf{\tilde{L}_t}$**:** Taking first-order conditions for these variables gives

$$\begin{aligned}
\lambda_t^N &= \lambda_t^L x_t^a - W_t + \lambda_t^{\tilde{N}} \\
\lambda_t^{\tilde{N}} &= \beta \mathbb{E}_t (1 - S_{t+1}) \lambda_{t+1}^N - \beta(1-\delta)\mathbb{E}_t(1 - Q_{t+1})\lambda_{t+1}^L x_{t+1}^a - \beta \mathbb{E}_t C_{\tilde{N},t+1} \\
\lambda_t^L &= A_t \lambda_t^Y + \lambda_t^{\tilde{L}} \\
\lambda_t^{\tilde{L}} &= \beta(1-\delta)\mathbb{E}_t(1 - Q_{t+1})\lambda_{t+1}^L
\end{aligned}$$

where λ_t^N is the value of an additional securely-attached employee (with the average productivity of employed hires that period, x_t^a) and λ_t^L is the value of improving the productivity of current employees. The multiplier λ_t^N is the marginal revenue from an additional unit of output, net of marginal price adjustment costs (i.e. it is real marginal cost). The separation rate S_t is defined below.

5 This discount is necessary so that firms still want to hire out of unemployed, even though the layoff rate for insecurely attached employees is high (so the expected duration of the match is low). Otherwise, the expected value of insecurely attached employees is negative in steady state.

The value of a hire depends on marginal revenue product $A_t\lambda_t^Y x_t^a$, minus the real wage W_t, plus the continuation value $\lambda_t^{\tilde{L}} x_t^a + \lambda_t^{\tilde{N}}$. The continuation value depends on the expected separation probability S_{t+1}, the expected value of employees next period λ_{t+1} (adjusted to account for the expected future idiosyncratic productivity of current hires), and the marginal reduction in recruiting costs next period from additional employees this period $C_{\tilde{N},t+1}$.

$\mathbf{H_t}$**,** $\mathbf{H_t^e}$ **and** $\mathbf{H_t^u}$**:** Taking first-order conditions with respect H_t, H_t^e and H_t^u gives

$$
\begin{aligned}
\lambda_t^{H^e} &= \lambda_t^N \\
\lambda_t^{H^u} &= \lambda_t^N + \xi - G_t^u \delta^u \lambda_t^{\tilde{N}} + (x_t^{a,u} - x_t^a)\lambda_t^L + \delta^u((1-G_t^u)x_t^{a,m} - x_t^{a,u})\lambda_t^{\tilde{L}}.
\end{aligned}
$$

where λ_t^j are Lagrange multipliers. The value of hires out of unemployment differs from λ_t^N because their wages are ξ lower, but they have a higher layoff probability and different average idiosyncratic productivities.

$\underline{\mathbf{x}}_\mathbf{t}$**,** $\underline{\mathbf{x}}_\mathbf{t}^\mathbf{u}$**,** $\underline{\mathbf{x}}_\mathbf{t}^\mathbf{m}$**:** Taking the first-order condition with respect to these thresholds gives

$$
\begin{aligned}
\lambda_t^N + \lambda_t^L(\underline{x}_t - x_t^a) &= 0 \\
\lambda_t^{H^u} + (\lambda_t^L - \delta^u \lambda_t^{\tilde{L}})(\underline{x}_t^u - x_t^{a,u}) &= 0 \\
\lambda_t^{\tilde{N}} + \lambda_t^{\tilde{L}} \underline{x}_t^m &= 0
\end{aligned}
$$

These equations just define the thresholds as the idiosyncratic productivity value such that the expected present value of a securely attached employee, an unemployed match, and insecurely attached employee with those productivity are zero.

$\mathbf{M_t}$ **and** $\mathbf{V_t}$**:** Taking first-order conditions with respect to M_t and V_t gives

$$
\frac{C_{V,t}}{q_t} + C_{M,t} = \phi_t^E(1-F_t)Ac_t^e\lambda_t^{H^e} + (1-\phi_t^E)(1-F_t^u)Ac_t^u\lambda_t^{H^u}.
$$

The left-hand side is the marginal recruiting cost of generating and screening a match. The right-hand side is the expected present discounted value of a match. It depends on the probability that the match is employed or unemployed, the probability that the match generates a hire, and the expected present discounted value of a hire.

$\mathbf{W_t}$**:** Taking the first-order condition with respect to the wage gives the wage Phillips curve

$$
\begin{aligned}
\left(1 + \Psi_t' \Pi_t^W \left(1 - \frac{\xi}{W_t}\frac{H_t^u}{N_t}\right)\right) N_t = \beta \mathbb{E}_t \Psi_{t+1}' \Pi_{t+1}^W \frac{W_{t+1}}{W_t}\left(1 - \frac{\xi}{W_{t+1}}\frac{H_{t+1}^u}{N_{t+1}}\right) N_{t+1} + \varepsilon_t^{H^e} H_t^e \frac{\lambda_t^N}{W_t} + \varepsilon_t^{H^u} H_t^u \frac{\lambda_t^{H^u}}{W_t} \\
- \varepsilon_t^Q Q_t (1-\delta F_t)\tilde{N}_{t-1}\frac{\lambda_t^N}{W_t} + \varepsilon_t^Q Q_t(1-\delta)\tilde{N}_{t-1}(x_t^a - \frac{\tilde{L}_{t-1}}{\tilde{N}_{t-1}})\frac{\lambda_t^L}{W_t}
\end{aligned}
$$

where we define the hiring and quits elasticities

$$
\begin{aligned}
\varepsilon_t^{H^e} &\equiv \frac{\partial H_t^e}{\partial W_t}\frac{W_t}{H_t^e} \\
\varepsilon_t^{H^u} &\equiv \frac{\partial H_t^u}{\partial W_t}\frac{W_t}{H_t^u} \\
\varepsilon_t^Q &\equiv \frac{\partial Q_t N_{t-1}}{\partial W_t}\frac{W_t}{Q_t N_{t-1}}.
\end{aligned}
$$

and

$$\Psi_t = \frac{\phi^w(\Pi_t^w)}{2}\left(\Pi_t^w - \Pi^w\right)^2$$
$$\Psi_t' = \phi^w(\Pi_t^w)\left(\Pi_t^w - \Pi^w\right).$$

If wage stickiness is symmetric, then $\phi^w(\Pi_t^w) = \phi^w$ is constant. If it is asymmetric, then $\phi^w(\Pi_t^w)$ is a decreasing function.

Note that firms' optimal real wage (in the absence of wage adjustment costs) is

$$W_t^* = \varepsilon_t^{H^e}\frac{H_t^e}{N_t}\lambda_t^N + \varepsilon_t^{H^u}\frac{H_t^u}{N_t}\lambda_t^{H^u} - \varepsilon_t^Q\frac{Q_t(1-\delta F_t)\tilde{N}_{t-1}}{N_t}\lambda_t^N + \varepsilon_t^Q\frac{Q_t(1-\delta)\tilde{N}_{t-1}}{N_t}(x_t^a - \frac{\tilde{L}_{t-1}}{\tilde{N}_{t-1}})\lambda_t^L.$$

It depends on the elasticities of hires and quits with respect to the wage, the rate of hires and quits as a share of employment, and the value of hires and employees. The final term is an adjustment to account for differences in average idiosyncratic productivity between existing employees and new hires.

Given nominal wage adjustment costs, nominal wages growth is determined by expected nominal wages growth and the gap between this optimal real wage and firms' actual real wage.

$\mathbf{P_t}$ and $\mathbf{Y_t}$: Taking first-order conditions for these variables gives

$$1 + \frac{1}{\theta-1}\Phi_t'\Pi_t = \beta\frac{1}{\theta-1}\mathbb{E}_t\Phi_{t+1}'\Pi_{t+1}\frac{Y_{t+1}}{Y_t} + \frac{\theta}{\theta-1}\lambda_t^Y$$

where

$$\Phi_t = \frac{\phi^p}{2}\left(\Pi_t - \Pi\right)^2$$
$$\Phi_t' = \phi^p\left(\Pi_t - \Pi\right).$$

This is a standard New Keynesian price Phillips curve.

2.2 Workers

All workers who are unemployed when shocks are revealed search for jobs. A share λ^{EE} of employed workers also search. The total number of searchers is then $\lambda^{EE}\tilde{N}_{t-1} + 1 - \tilde{N}_{t-1}$, and the effective share of employed searchers is

$$\phi_t^E = \frac{\lambda^{EE}\tilde{N}_{t-1}}{\lambda^{EE}\tilde{N}_{t-1} + 1 - \tilde{N}_{t-1}}.$$

Those who enter unemployment after shocks are revealed, either because they are laid off or because they quit to unemployment, do not search in that period.[6]

A share λ^{EU} of employed workers consider quitting to unemployment.

6 This means that even if hiring costs went to zero, unemployment would remain above zero. If the newly unemployed were allowed to search, this would raise the average number of searchers, especially in periods where layoffs are high. Workers hired last period who are laid off before shocks are revealed can search. This is to avoid H_{t-1}^u or N_{t-1} being a state variable.

Workers' only role in the model is to determine the labour supply schedule faced by firms. They do so by determining the hiring and quits elasticities $\varepsilon_t^{H^e}$, $\varepsilon_t^{H^u}$ and ε_t^{Q} via the functions $Ac_t^e(W_t)$, $Ac_t^u(W_t)$ and $Q(W_t)$.

Workers draw an idiosyncratic preferences for firms when they match, which they compare to any wage differential. These preferences are drawn from a Gumbel distribution with parameter γ. If a firm pays wage W_t, then the probability that a worker prefers a different firm that has made them an offer is $\int \frac{w^\gamma}{w^\gamma + W_t^\gamma} d\mu_t(w)$ where $\mu_t(w)$ is the distribution of wages offered by firms.[7]

Unemployment benefits are $b_t = bW_t$, where W_t is the aggregate wage.[8] If a firm pays wage W_t, then the probability that a worker considering unemployment prefers it is $\frac{b_t^\gamma}{b_t^\gamma + W_t^\gamma}$.

Therefore the quits rate and elasticity are

$$Q(W_t) = \lambda^{EE} f_t(1-F_t) \int \frac{w^\gamma}{w^\gamma + W_t^\gamma} d\mu_t^v(w) + \lambda^{EU} \frac{b_t^\gamma}{b_t^\gamma + W_t^\gamma}$$

$$Q_t = \lambda^{EE} f_t(1-F_t)\frac{1}{2} + \lambda^{EU} \frac{b^\gamma}{b^\gamma + 1}$$

$$\varepsilon_t^Q = -\gamma \frac{\lambda^{EE} f_t(1-F_t)\frac{1}{4} + \lambda^{EU} \frac{\gamma b^\gamma}{(b^\gamma+1)^2}}{\lambda^{EE} f_t(1-F_t)\frac{1}{2} + \lambda^{EU} \frac{b^\gamma}{b^\gamma+1}}$$

where f_t is the matching-finding rate, which is determined by aggregate matching efficiency and labour market tightness.

The hiring rates and elasticities are

$$H_t^e(W_t) = \phi_t^E M_t(1-F_t) \int \frac{W_t^\gamma}{w^\gamma + W_t^\gamma} d\mu_t(w)$$

$$H_t^e = \phi_t^E \frac{1}{2}(1-F_t) q_t V_t$$

$$\varepsilon_t^{H^e} = \gamma \frac{1}{2}$$

$$H_t^u(W_t) = (1-\phi_t^E) M_t (1-F_t^u) \frac{W_t^\gamma}{b_t^\gamma + W_t^\gamma}$$

$$H_t^u = (1-\phi_t^E) \frac{1}{b^\gamma + 1}(1-F_t^u) q_t V_t$$

$$\varepsilon_t^{H^u} = \gamma \frac{b^\gamma}{b^\gamma + 1}.$$

7 As in Bloesch *et al* (2024), workers are myopic and only consider current-period real wages. Bloesch *et al* (2024) suggest that modelling more forward-looking workers adds considerable complexity without little change in the results. This probability also implies that employees redraw preferences for their current employer every time they match with another firm. Otherwise, their preference for their current employer should be higher on average (given they chose to work there).

8 The assumption that unemployment benefits track real wages, which is the same as in Bloesch *et al* (2024), means that there is no labour supply response at an aggregate level to shocks. The offer-acceptance rate for unemployed applicants and the quit-to-unemployment rate are both constant. If this assumption was relaxed, then we could model the labour supply response to shocks (and consider the effect of labour supply shocks).

2.3 Policy and aggregate variables

Labour market tightness: Tightness is

$$\theta_t = \frac{V_t}{\lambda^{EE}\tilde{N}_{t-1} + 1 - \tilde{N}_{t-1}}.$$

Using the DRW matching function gives match-finding and vacancy-matching rates

$$f_t = (1+\theta_t^{-\alpha})^{-\frac{1}{\alpha}}$$
$$q_t = (1+\theta_t^{\alpha})^{-\frac{1}{\alpha}}.$$

Monetary policy: Policy tries to implement a flexible inflation target, but is subject to various shocks (e.g. it cannot fully offset all demand shocks immediately). Therefore:

$$\ln \Pi_t - \ln \Pi^{target} + \gamma^p \left(N_t - N^{target}\right) = \ln M_t$$

where M_t is an exogenous nominal demand shock.

2.4 Equilibrium, solution and calibration

We assume that firms have rational expectations, which implies that they understand the interaction between nonlinearities in the economy and aggregate risk when forming their expectations. This means, for example, that in the presence of downward nominal wage rigidity, firms will set lower wages even in steady state, given the risk that it will be very costly for them to reduce wages if negative shocks occur in the future.

We compute the global solution to the nonlinear model, so that we can explore how the interaction between nonlinearities and aggregate risk affects expectations and dynamics. The state variables are employment $\tilde{N}_{t-1}$ (after insecurely attached employees are laid off), real wages W_{t-1}, the average idiosyncratic productivity of employees $\bar{x}_{t-1}$, and the aggregate productivity and demand shocks, A_t and M_t.

The model is calibrated so that steady-state values for unemployment and key labour-market flows are broadly similar to their values Australian data around 2025, as well as to match the standard deviation of the unemployment rate over 1980 to 2019 and generate a similar positive skewness of unemployment rate changes.

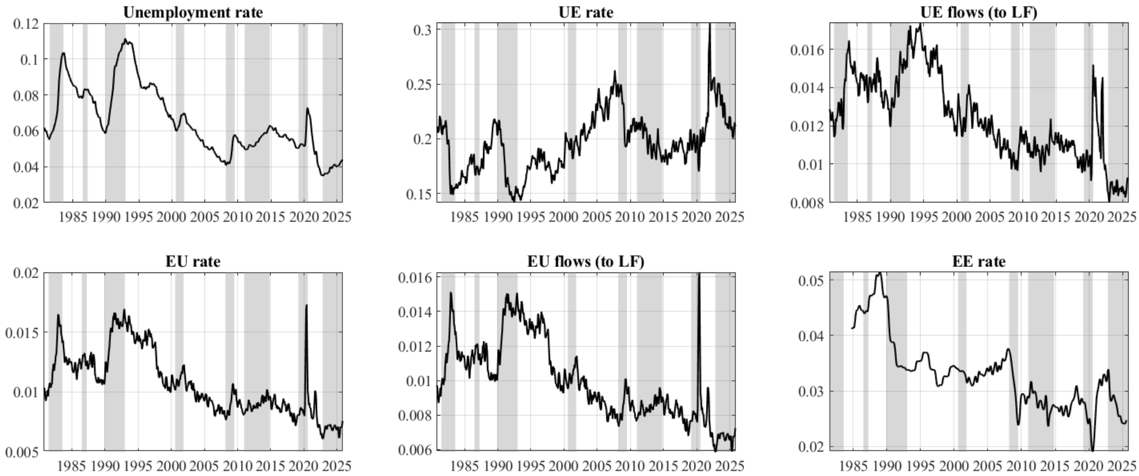
See Appendix 5 for more detail on the calibration and solution method.

3. How well can we match the dynamics of the labour market in the data?

3.1 Comparing the model to labour-market dynamics in the data

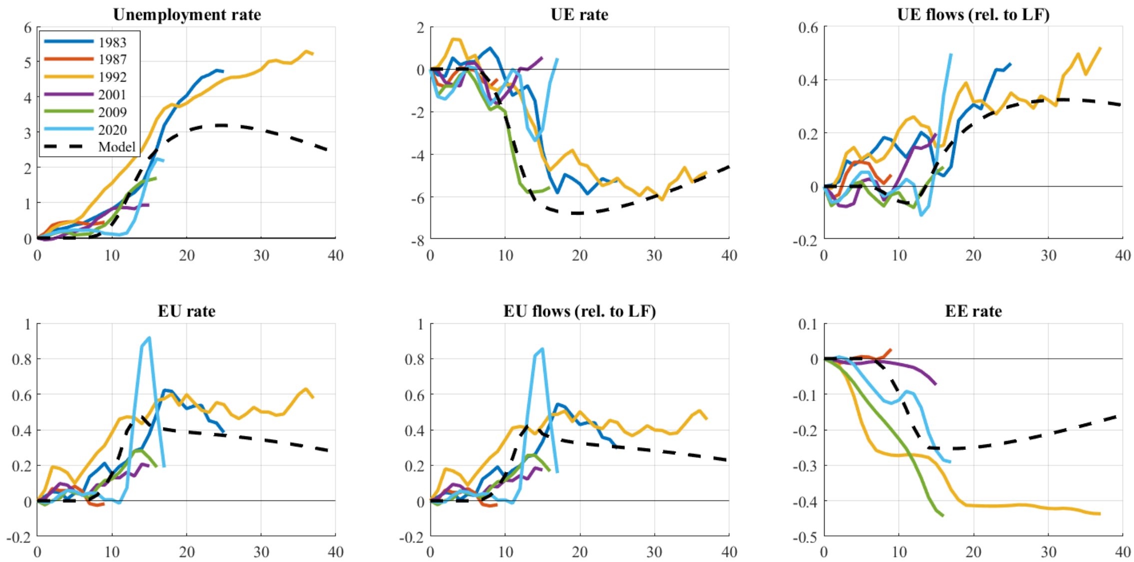
In this section, we compare the dynamics of unemployment and labour-market flows in the model to Australian data. Figure 2 illustrates the path of transition rates and flows between labour-market states in Australia since 1980. It shows that the UE rate is negative correlated with unemployment, even though UE flows (as a proportion of the labour force) are positively correlated. UE flows increase when the pool of unemployed is larger, but this increase is not enough for the UE *rate* to increase.

Figure 2: Labour-market transition rates and flows in Australia



Note: The UE and EU flows in the data are divided by the labour force size to make them comparable to the model flows. The shaded regions represent contractions, which are identified using the algorithm in Dupraz *et al* (2025).

Figure 3: Comparing recessions in the model and the data



Note: The UE and EU flows in the data are divided by the labour force size to make them comparable to the model flows.

The figure also shows that the EU rate and EU flows are postively correlated with unemployment, and the EE rate (i.e. job-to-job transition rate) is negatively correlated (at a cyclical frequency).

Figure 3 compares a stylised recession in our model to recessions in the data since 1980.[9] The model downturn is generated with a sequence of six demand shocks (over six months) calibrated to produce a similar path for unemployment to the downturns in the data. The paths for transition rates and flows from the model are broadly similar to the data. In particular, the UE rate falls while UE flows increase, and the magnitude of all responses is comparable to the data.

9 We exclude the 2010-14 and 2022-25 upswings because they involved a gradual increase in unemployment rather than a spike.

Next, we consider whether our model can reproduce the 'plucking' or asymmetric 'sharp spike' and 'slow decline' patterns we see in the unemployment rate data. One measure of this pattern is the skewness of unemployment rate changes. In the data, this moment is quite positive, reflecting frequent small decreases and occasional large increases (Table 1) (Sichel (1993) called this a 'steepness' asymmetry). Standard search-and-matching models tend to generate negative skewness in unemployment changes (Ferraro 2023). In contrast, under the current calibration, simulations of our model generate a substantially positive skewness of unemployment rate changes, although not quite as large as in the data.

We can also compare other moments of the unemployment rate and moments of the unemployment-to-employment (UE) and employment-to-unemployment (EU) transition rates in our model to the data. The model generates somewhat higher variance and negative skewness in the UE rate, whereas the UE rate is positively skewed in Australian data over this sample period. In US data, the UE rate has higher variance and is negatively skewed (see Appendix A.3). The model matches the variance and skewness of the EU rate well, but generates more skewness in changes in the EU rate than in the data.

Table 1: Comparing moments of quarterly unemployment and transition rates

	Unemployment rate		UE rate		EU rate	
	Model	Data	Model	Data	Model	Data
Standard deviation	1.46	1.56	3.22	2.42	0.19	0.19
Skewness	1.12	0.59	-0.38	0.40	0.52	0.57
Skewness of changes	1.37	1.71	-0.74	-0.62	2.02	0.69

Notes: These moments use Australian data from 1980 to 2019, detrended using estimates from Ballantyne and Cusbert (2025). See Appendix A.3 for moments using undetrended data and using US data.

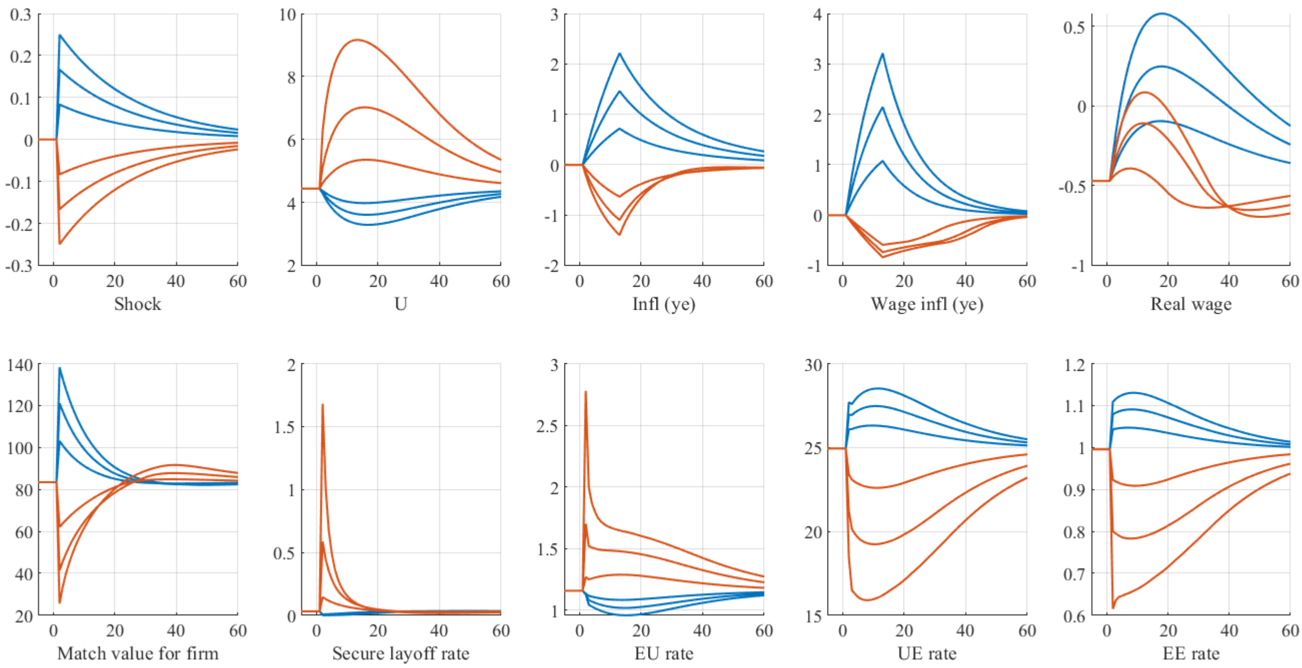
3.2 Explaining the model's dynamics

The IRFs in Figure 4 demonstrate why we can match these moments. The responses are strongly nonlinear. Large negative shocks generate a large increase in the unemployment rate (disproportionately more than small negative shocks), whereas positive shocks do not reduce it very much. Unemployment recovers very slowly after an initial spike.

To explore why the model is able to generate these asymmetric dynamics, Table 2 compares the model's moments when three key frictions are removed, either one at a time or all together. First, the downward nominal wage rigidity is removed by making wage adjustment costs symmetric. The next column removes insecurely attached workers, so that all workers have the same layoff rate. The next column removes convexity in recruiting costs, making them (almost) linear. The final column removes all three frictions. In each case, we recalibrate the model so that it generates the same steady-state unemployment rate and flows, and the same variance in unemployment. Figure 5 compares the response of each version of the model to positive and negative demand shocks.

When all three frictions are removed (the last column in Table 2), the degree of asymmetry declines and the skewness of unemployment rate changes is much lower. Unlike the standard DMP model (Ferraro 2023), the skewness of unemployment changes remains positive, likely because layoffs are still endogenous, which generates some asymmetry. Figure 5 shows that unemployment recovers more rapidly, especially the UE rate. The value of a match is a forward-looking object, determined largely by expected future surplus, and therefore rises quickly after the shock peaks.

Figure 4: Response to aggregate demand shocks



Note: The economy is initially at steady state.

When unemployment is high, the vacancy-filling rate is also high, so marginal recruiting costs fall. Unemployed searchers make up a much larger proportion of total searchers, so for a given amount of hiring, hires out of unemployment are higher.

Table 2: Moments for different versions of model

	Data	Model	Insecurely attached workers + convex recruiting costs	DNWR + convex recruiting costs	DNWR + insecurely attached workers	None
Unemployment rate						
Standard deviation	1.56	1.44	1.45	1.47	1.46	1.47
Skewness	0.59	1.10	0.87	0.96	1.02	0.66
Skewness of changes	1.71	1.30	1.15	0.25	0.84	0.11
UE rate						
Standard deviation	2.42	3.25	3.78	1.70	5.55	1.97
Skewness	0.40	-0.35	-0.15	-0.60	-0.14	-0.04
Skewness of changes	-0.62	-0.71	-0.65	-0.12	-0.14	-0.01
EU rate						
Standard deviation	0.19	0.18	0.19	0.33	0.20	0.39
Skewness	0.57	0.48	0.23	0.81	0.86	0.62
Skewness of changes	0.69	1.97	1.75	-0.07	0.67	0.02

Notes: The 'Data' column is based on detrended Australian data from 1980 to 2019. The 'Model' column includes all three frictions. The next three columns remove one friction at a time. The last column removes all three frictions. See Table B2 for moments where each friction is included on its own.

Below we explain the effect of each of the three frictions:[10]

- **Convex recruiting costs:** The convexity of recruiting costs moderates the response of hiring to fluctuations in match value. Without this convexity, hiring responds much more to fluctuations in match value, so the UE rate is too volatile (see the fifth column in Table 2 and the yellow lines in Figure 5). After a negative shock, UE flows initially decline over the first year and the EU rate is near steady state shortly after the initial spike. This reduces the skewness in unemployment rate changes.
- **Insecurely attached workers:** The presence of insecurely attached workers is the most significant contributor to the skewness in unemployment rate changes (see the fourth column in Table 2 and the red lines in Figure 5). It does so in two ways. First, the layoff rate for securely attached employees provides a highly nonlinear component to the EU rate. In steady state, very few securely attached employees are laid off and the mass of employees near the layoff threshold is small. Therefore, layoffs vary little for positive or small negative shocks. But when large negative shocks occur, the mass of employees above the layoff threshold is much larger, so there is a spike in layoffs. This helps generates asymmetric spikes in unemployment, although it does not generate persistence in the EU rate once match values recover.[11] But this is where the insecurely attached component of layoffs helps. Their layoff rate is much higher, so when unemployment is high and the flow of hires out of unemployment rises above steady state, the layoff rate also rises. The unemployed may cycle through several short-term jobs before regaining secure employment. This feature substantially slows the recovery in unemployment and helps generate persistence and skewness in the EU rate.
- **Asymmetric nominal wage stickiness:** After a positive shock, nominal and real wages growth increases, offsetting a lot of the increase in marginal revenue product. This moderates and shortens the increase in match values for firms, dampening the incentive to increase employment or any reduction in layoffs. In contrast, after a negative shock nominal wages growth does not decrease very much. In the case of a negative demand shock, real wages growth actually increases (due to the decline in inflation). This both amplifies and prolongs the decline in match values for firms, which helps to generate both the asymmetric plucks and the slow recoveries in unemployment (see the third column in Table 2 and the blue lines in Figure 5).

4. Phillips curve and NAIRU

4.1 Nonlinear Phillips curve

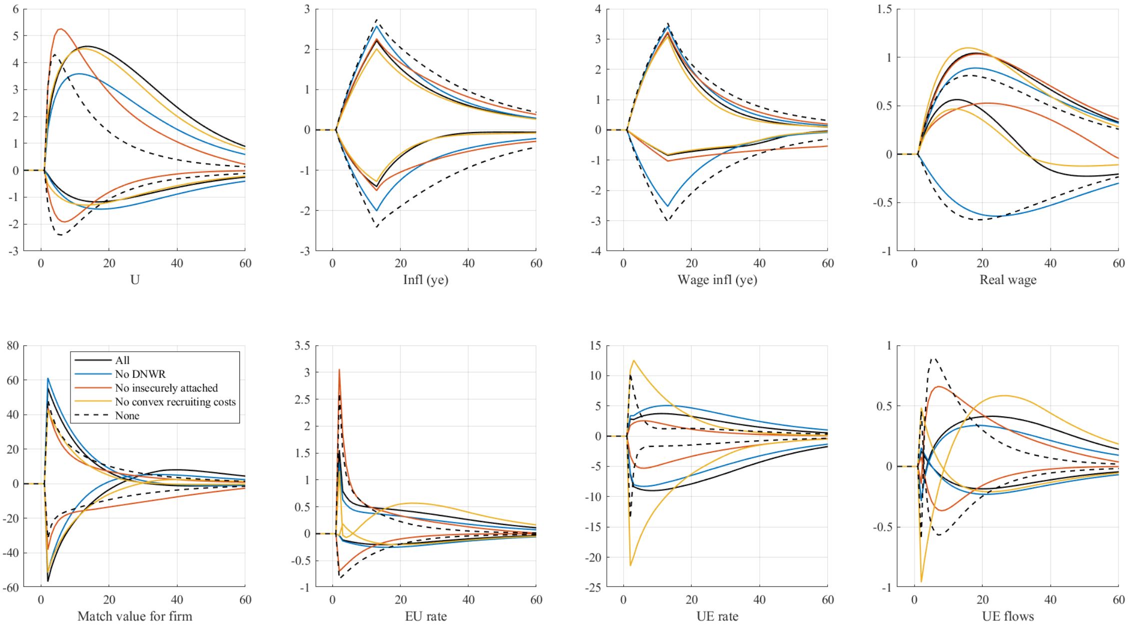
The model implies that the relationship between inflation and unemployment (i.e. the Phillips curve) is nonlinear and state-dependent. Figures 6 and 7 show this relationship by plotting inflation against unemployment conditional on different initial values for unemployment or real wages.[12] The Phillips curve is much steeper at low rates of unemployment, but this steepening occurs at higher

10 Dupraz *et al* (2025) also include insecurely attached workers and downward nominal wage rigidities to generate asymmetry in unemployment dynamics.

11 The layoff rate for securely attached employees moves contemporaneously with match values, and is therefore only as persistent as match values.

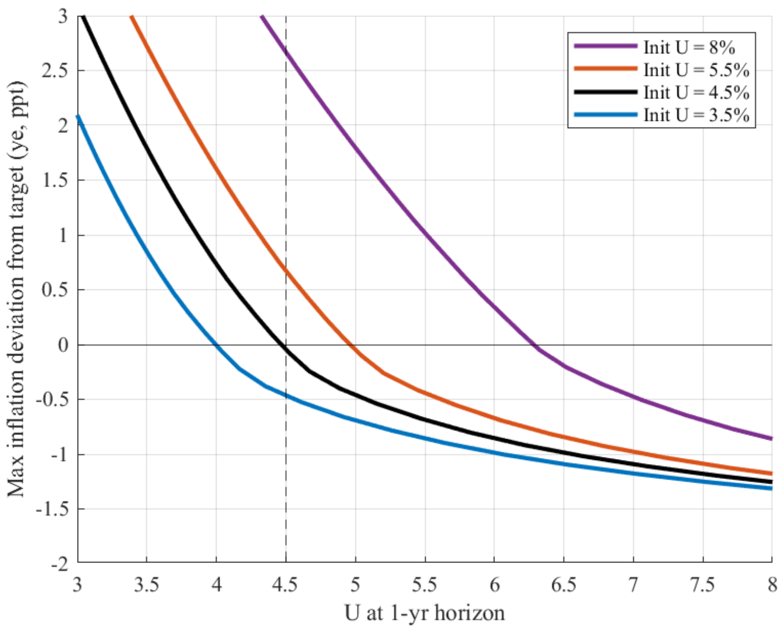
12 Specifically, we vary the policy/demand shock variable and plot the maximum deviation of inflation from target against the unemployment rate for each value of this shock. This accounts for the dynamic relationship between inflation and unemployment in the model, which is largely not contemporaneous. The peak unemployment response tends to be quite lagged, because the model includes many labour-market frictions, but inflation responds very rapidly, because expectations are forward-looking and based on full information. Introducing features like indexation, backward-looking expectations, inattention or imperfect information could slow the inflation response.

Figure 5: Response to aggregate demand shocks with different versions of model



Note: There are two shocks for each model: the largest positive and largest negative shocks from Figure 4. The economy is initially at steady state.

Figure 6: Phillips curve given initial unemployment



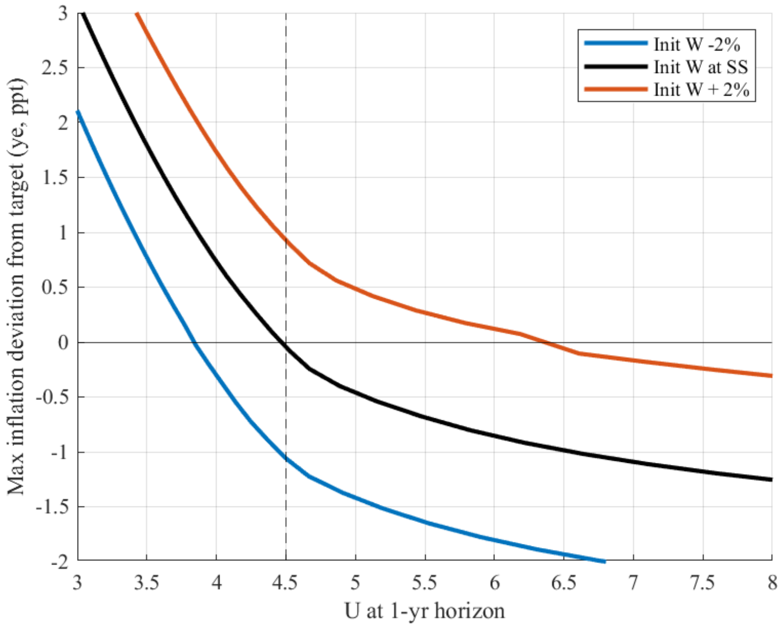
Note: The Phillips curves are constructed by varying the demand shock and plotting the inflation and unemployment outcomes that it traces out. The dashed vertical line is steady-state unemployment.

unemployment rates when the initial unemployment rate is higher. When the initial level of real wages is higher, the Phillips curve shifts upwards.

4.2 Short-run NAIRU

Figures 6 and 7 show that the unemployment rate consistent with maintaining inflation at target (i.e. the intersection of the Phillips curves with the x-axis) is state-dependent. At steady state, it is

Figure 7: Phillips curve given initial level of real wages



Note: The Phillips curves are constructed by varying the demand shock and plotting the inflation and unemployment outcomes that it traces out. The dashed vertical line is steady-state unemployment.

4.5 percent under our calibration of the model. But if unemployment or real wages increase, then the Phillips curve shifts and the one-year-ahead unemployment forecast consistent with at-target inflation increases.

We can therefore construct a 'short-run NAIRU' concept in our model. We define it as follows: if policymakers wanted to eliminate any deviations in inflation from target stemming excessive or insufficient demand in the labour market, what unemployment rate at a one-year horizon would be required? This is essentially the intercept with the x-axis in Figures 6 and 7. At steady state, it coincides with the long-run NIARU (i.e. the intersection of the steady-state Phillips curve in black with the x-axis).

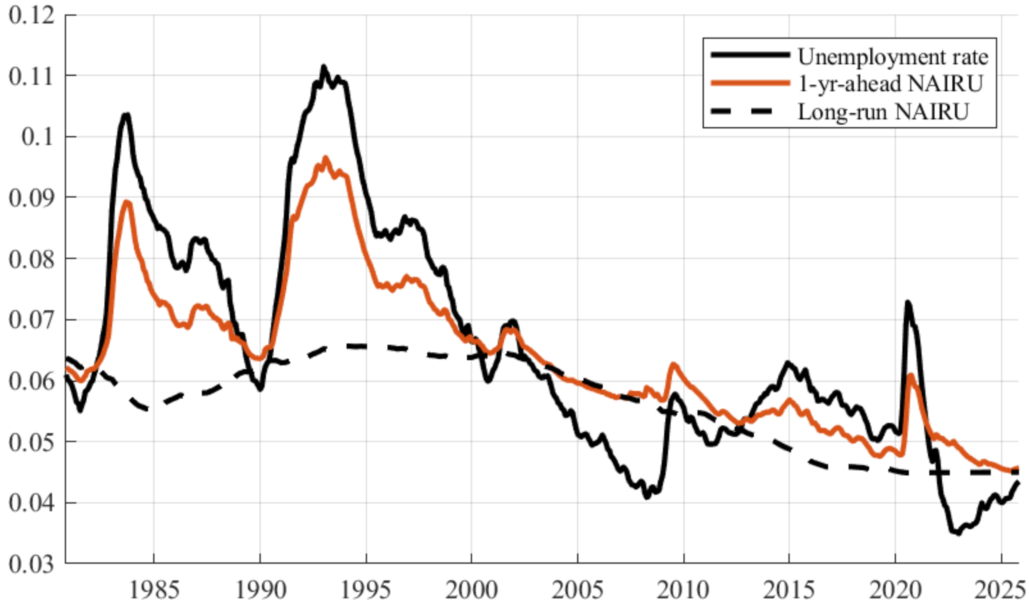
Figure 8 uses the model to calculate the historical path of the 'short-run NAIRU' in Australia from 1980 to 2025. It is calculated by: (i) calculating the sequence of demand shocks that in our model replicates the historical path of the unemployment rate;[13] (ii) using the model to simulate the inflation generated by this sequence of demand shocks, which we define as the 'labour-market' component of inflation;[14] (iii) given the state of the economy in each period, calculating the sequence of demand shocks consistent with forecast inflation being at target; and (iv) calculating the the one-year-ahead forecast for the unemployment rate given that sequence of shocks and defining it as as the 'one-year-ahead NAIRU' for that period.[15]

13 For simplicity, we are assuming that historical unemployment has been driven by only demand shocks. It is likely that other shocks also drove some of the variation in the unemployment rate.

14 This simulated inflation series is in Figure B1.

15 We are ignoring here potential interactions between supply-driven inflation and the labour market. For example, an inflationary supply shock might make it easier to reduce real wages, allowing the labour-market-driven component of inflation to fall without as much of an increase in unemployment.

Figure 8: Short-run NAIRU



Note: The long-run NAIRU estimate is from Ballantyne and Cusbert (2025).

Figure 8 shows that the short-run NAIRU varies cyclically much more than the long-run NAIRU.[16] When unemployment is above trend, the short-run NAIRU tends to increase and track the actual unemployment rate. But there is some asymmetry: in the pre-GFC period when unemployment fell below trend, the short-run NAIRU did not decline. In the recent period, the short-run NAIRU was above the long-run NAIRU, even though actual unemployment was below it. In a tight labour market, unemployment declines, which shifts the Phillips curve to the left, but real wages rise, which shifts the Phillips curve up. The effect on the short-run NAIRU is ambiguous.

4.3 Long-run NAIRU

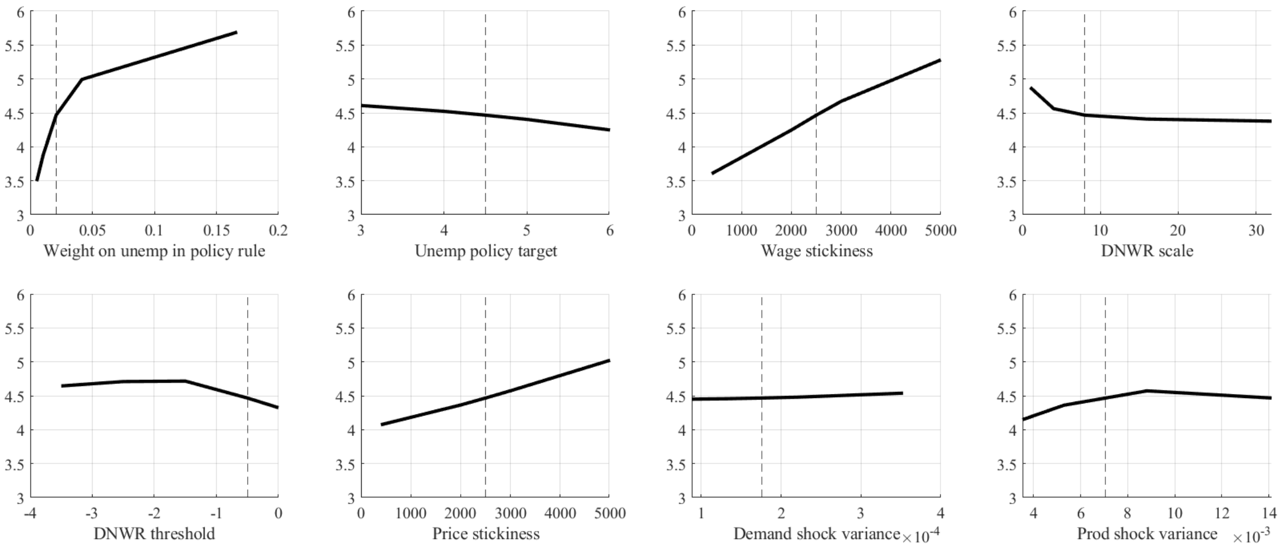
Although the dynamics of the model describe only cyclical fluctuations in unemployment, the model's long-run properties can be used to consider the determinants of the long-run NAIRU (i.e. the NAIRU concept that is most commonly estimated by central banks using latent-variable models with a unit-root NAIRU process, e.g. (Ballantyne and Cusbert 2025)).

The deterministic steady-state unemployment rate in the model is determined by parameters such as recruiting costs, on-the-job search effort, and firms' labour market monopsony power determine the long-run NAIRU in the model. But this concept is not exactly analogous to the long-run NAIRU, because it assumes that agents believe there will be no shocks in the future. The long-run NAIRU is instead the stochastic steady-state unemployment rate, which is the unemployment rate in the absence of shocks but assuming agents still believe shocks will occur in the future according to their specified distribution.

Since we compute the global nonlinear solution to the model with rational expectations and aggregate risk, we can consider how changes in cyclical properties of the model (e.g. shock volatility, price and

16 Hall and Kudlyak (n.d.) also discuss the concept of a short-run NAIRU that fluctuates cyclically.

Figure 9: Effect of parameters on the long-run NAIRU



Note: The dashed vertical line represents the calibration in the baseline model.

wage stickiness, monetary policy) affect the long-run NAIRU via agents' response to expectations and risk. Figure 9 shows how the long-run NAIRU changes when certain parameters are varied.

Increasing the weight on unemployment in the policy rule *increases* the long-run NAIRU. This may reflect a kind of level-variance trade off: if policy stabilises labour demand to a greater extent, the downward nominal wage rigidity will bind less often. Firms understand this decline in the risk of incurring wage adjustment costs in the future, and are therefore more willing to set higher real wages in steady state, which reduces match values and raises the level of unemployment in steady state.

Increases in the stickiness of wages or prices also increases the long-run NAIRU. If firms are less able to raise wages in response to positive shocks, they will set higher real wages in steady state, which increases steady-state unemployment. If prices are stickier, then nominal wages do not need to decline as much in response to negative demand shocks, which means that downward nominal wage rigidities bind less often. Again, firms will set higher real wages in steady state and employ fewer workers.

This results may be affected by the calibration of the model. For example, a greater variance in productivity shocks compared to demand shocks could change how parameters affect the long-run NAIRU.

5. Conclusion

We construct a model of the labour-market that can generate the asymmetric dynamics of unemployment in the data (given symmetric shocks) and can be used to study the implications for inflation. We find that endogenous layoffs, a 'slippery' job ladder, downward nominal wage rigidity, and convex recruiting costs are the key frictions that produce the asymmetric dynamics. The model can generate a substantially positive skewness in unemployment changes, which is a feature of the data but not most existing structural models of the labour market. The model implies that the short-run Phillips curve is nonlinear and state-dependent, and that the short-run NAIRU fluctuates cyclically and asymmetrically, tending to increase when unemployment is above trend, but may not decline when unemployment is below trend. The long-run NAIRU is affected by cyclical factors (e.g. shock volatility, nominal rigidities, policy regime), because the nonlinear cyclical dynamics and aggregate risk interact to affect firms' expectations and employment decisions even in the absence of shocks.

Appendix A: Further model details

A.1 Equilibrium conditions

$$
\begin{aligned}
\underline{x}_t &= \frac{\lambda_t^L x_t^a - \lambda_t^N}{\lambda_t^L}, \quad F_t = F(\underline{x}_t), \quad x_t^a = \frac{1}{1-F_t}\int_{\underline{x}_t}^{x^h} x\,dF(x) \\
\underline{x}_t^u &= \frac{(\lambda_t^L - \delta^u \lambda_t^{\tilde{L}})x_t^{a,u} - \lambda_t^{H^u}}{\lambda_t^L - \delta^u \lambda_t^{\tilde{L}}}, \quad F_t^u = F^u(\underline{x}_t^u), \quad x_t^{a,u} = \frac{1}{1-F_t^u}\int_{\underline{x}_t^u}^{x^h} x\,dF^u(x) \\
\underline{x}_t^m &= -\frac{\lambda_t^{\tilde{N}}}{\lambda_t^{\tilde{L}}}, \quad G_t = G(\underline{x}_t), \quad x_t^{a,m} = \frac{1}{1-G_t}\int_{\underline{x}_t^m}^{x^h} x\,dG(x) \\
\phi_t^E &= \frac{\lambda^{EE}\tilde{N}_{t-1}}{\lambda^{EE}\tilde{N}_{t-1} + 1 - \tilde{N}_{t-1}} \\
\frac{C_{V,t}}{q_t} + C_{M,t} &= \phi_t^E(1-F_t)\frac{1}{2}\lambda_t^N + (1-\phi_t^E)(1-F_t^u)\frac{1}{1+b^\gamma}\lambda_t^{H^u} \\
\theta_t &= \frac{V_t}{\lambda^{EE}\tilde{N}_{t-1} + 1 - \tilde{N}_{t-1}}, \quad f_t = (1+\theta_t^{-\alpha})^{-\frac{1}{\alpha}}, \quad q_t = (1+\theta_t^{\alpha})^{-\frac{1}{\alpha}} \\
Q_t &= \lambda^{EE} f_t(1-F_t)\frac{1}{2} + \lambda^{EU}\frac{b^\gamma}{b^\gamma+1}, \quad S_t = Q_t + (1-Q_t)\delta F_t \\
H_t &= H_t^e + H_t^u, \quad H_t^e = \phi_t^E(1-F_t)\frac{1}{2}q_t V_t, \quad H_t^u = (1-\phi_t^E)(1-F_t^u)\frac{1}{b^\gamma+1}q_t V_t \\
N_t &= H_t + (1-S_t)\tilde{N}_{t-1}, \quad \tilde{N}_t = N_t - G_t\delta^u H_t^u \\
L_t &= \left(N_t - (1-Q_t)(1-\delta)\tilde{N}_{t-1} - H_t^u\right)x_t^a + H_t^u x_t^{a,u} + (1-Q_t)(1-\delta)\tilde{L}_{t-1} \\
\tilde{L}_t &= L_t + \delta^u H_t^u\left((1-G_t)x_t^{a,m} - x_t^{a,u}\right) \\
\varepsilon_t^{H^e} &= \gamma\frac{1}{2}, \quad \varepsilon_t^{H^u} = \gamma\frac{b^\gamma}{1+b^\gamma}, \quad \varepsilon_t^Q = -\gamma\frac{\lambda^{EE}f_t(1-F_t)\frac{1}{4} + \lambda^{EU}\frac{b^\gamma}{(b^\gamma+1)^2}}{\lambda^{EE}f_t(1-F_t)\frac{1}{2} + \lambda^{EU}\frac{b^\gamma}{b^\gamma+1}} \\
Y_t &= A_t L_t \\
\frac{\Pi_t}{\Pi^{target}} &= M_t\exp(-\gamma^p(N_t - N^{target})) \\
\Phi_t &= \frac{\phi^p}{2}(\Pi_t - \Pi)^2, \quad \Psi_t = \frac{\phi^w}{2}\left(\Pi_t^w - \Pi\right)^2 \\
W_t &= \frac{\Pi_t^W}{\Pi_t}W_{t-1} \\
\lambda_t^N &= \lambda_t^L x_t^a - W_t + \lambda_t^{\tilde{N}} \\
\lambda_t^L &= A_t\lambda_t^Y + \lambda_t^{\tilde{L}} \\
\lambda_t^{H^u} &= \lambda_t^N + \xi - G_t\delta^u\lambda_t^{\tilde{N}} + (x_t^{a,u} - x_t^a)\lambda_t^L + \delta^u((1-G_t^u)x_t^{a,m} - x_t^{a,u})\lambda_t^{\tilde{L}} \\
\lambda_t^{\tilde{N}} &= \beta\mathbb{E}_t(1-S_{t+1})\lambda_{t+1}^N - \beta(1-\delta)\mathbb{E}_t(1-Q_{t+1})\lambda_{t+1}^L x_{t+1}^a - \beta\mathbb{E}_t C_{\tilde{N},t+1} \\
\lambda_t^{\tilde{L}} &= \beta(1-\delta)\mathbb{E}_t(1-Q_{t+1})\lambda_{t+1}^L \\
1 + \Phi_t'\Pi_t &= \beta\mathbb{E}_t\Phi_{t+1}'\Pi_{t+1}\frac{Y_{t+1}}{Y_t} + \lambda_t^Y \\
\left(1 + \Psi_t'\Pi_t^W\left(1 - \frac{\xi}{W_t}\frac{H_t^u}{N_t}\right)\right)N_t &= \beta\mathbb{E}_t\Psi_{t+1}'\Pi_{t+1}^W\frac{W_{t+1}}{W_t}\left(1 - \frac{\xi}{W_{t+1}}\frac{H_{t+1}^u}{N_{t+1}}\right)N_{t+1} + \varepsilon_t^{H^e}H_t^e\frac{\lambda_t^N}{W_t} + \varepsilon_t^{H^u}H_t^u\frac{\lambda_t^{H^u}}{W_t} \\
&\quad - \varepsilon_t^Q Q_t(1-\delta F_t)\tilde{N}_{t-1}\frac{\lambda_t^N}{W_t} + \varepsilon_t^Q Q_t(1-\delta)\tilde{N}_{t-1}(x_t^a - \frac{\tilde{L}_{t-1}}{\tilde{N}_{t-1}})\frac{\lambda_t^L}{W_t}
\end{aligned}
$$

A.2 Calibration

Labour flows and stocks: In steady state, hires from unemployment equal quits to unemployment and layoffs:

$$H^u = \left(Q^u + \tilde{F}^s\right) N + G\delta^u H^u.$$

Therefore:

$$H^u = \frac{Q^u + \tilde{F}^s}{1 - G\delta^u} N$$
$$EU = \frac{Q^u + \tilde{F}^s}{1 - G\delta^u}$$

We set $G = 0.8$ and $\delta^u = 1$. Then we set steady state values for N, Q^u, and $\tilde{F}^s$ so that the stochastic steady states for N, UE, and EU match their values in the data (somewhere between 2019 values and 2025 values, which means around 4-4.5% unemployment, 20-25% UE rate, and 1% EU rate). We assume the quit-to-unemployment rate is around 0.2%, so the layoff rate is around 0.8%, and the secure layoff rate is around 0.05%.[17]

We set the steady-state EE rate to try to match its value in the data (around 1-1.5%).

Match productivity distributions: We set $\delta = 0.1$, so that 10% of employees draw a new productivity each month (and can be laid off). Setting δ too high means that match productivities are not very persistent and so have little effect on expected match surplus. Setting δ too low means that layoffs cannot rise much.

We assume that firms do not know the productivity of unemployed matches, so they accept all of them ($F^u = 0$).

The match productivity distributions F, F^u and G are all truncated lognormal. We set the mean of the main distribution $\mu_x = 0.1$ and the mean of the distribution for unemployed matches $\mu_{x,u} = -0.5$. The wage of newly hired unemployed workers is a fixed amount lower than the aggregate wage: $W_t - W_t^u = \xi = 0.5$. The standard deviation of the distribution that new hires out of unemployment draw from after their first period, G, is set to be 3 times larger than the standard deviations of the main distribution F and the distribution for unemployed matches before they are hired F^u.[18] The remaining parameters of the distributions (i.e. the truncation point, the standard deviation, and the mean of G) are then determined by the steady-state flows.

Matching function and recruiting costs: The matching function elasticity $\alpha = 0.5$. The convexity parameter for recruiting costs is set $\chi = 4$. We assume no training cost, $\kappa^T = 0$, and then κ and κ^v are calibrated so that 20% of total recruiting costs are per-vacancy, while 80% are per-match.

Note that $C_{\tilde{N},t+1} = -\chi \frac{C_{t+1}}{\tilde{N}_t}$ and $(1+\chi)\frac{C_t}{M_t} = \frac{C_{V,t}}{q_t} + C_{M,t} = \frac{H_t^e}{M_t}\lambda_t^N + \frac{H_t^u}{M_t}\lambda_t^{H^u}$, so $C_{\tilde{N},t+1} = -\frac{\chi}{1+\chi}\frac{H_{t+1}^e\lambda_{t+1}^N + H_{t+1}^u\lambda_{t+1}^{H^u}}{\tilde{N}_t}$.

17 Assuming a lot of insecure layoffs and few secure layoffs in steady state (i.e. high G) helps to generate skew in unemployment changes and slow recoveries. In the Dupraz, Nakamura and Steinsson model, the exogenous separation rate for insecurely-attached workers is 96%, compared to 0.02% for securely-attached workers. They say this is the order of magnitude required to generate slow recoveries.

18 A higher variance for G seems to help generate skewness in unemployment changes.

Wage setting: The hiring and quits elasticities are

$$\varepsilon^{H^e} = \gamma \frac{1}{2}, \quad \varepsilon^{H^u} = \gamma \frac{b^\gamma}{b^\gamma + 1}, \quad \varepsilon^Q = -\gamma \frac{\lambda^{EE} f(1-F)Ac^{e\prime} + \lambda^{EU} Ac^{u\prime}}{\lambda^{EE} f(1-F)Ac^e + \lambda^{EU}(1-Ac^u)}.$$

The steady-state flow rates determine λ^{EE} and λ^{EU}. We set $b = 0.75$. In steady state:

$$WN = \varepsilon^{H^e} H^e \lambda^N + \varepsilon^{H^u} H^u \lambda^{H^u} \frac{W}{W-\xi} - \varepsilon^Q Q(1-\delta F)\tilde{N}\lambda^N + \varepsilon^Q Q(1-\delta)\tilde{N}(x^a - \frac{\tilde{L}}{\tilde{N}})\lambda^L$$

$$\lambda^N = \frac{x^a - W - \beta C_N}{1-\beta(1-S)}$$

$$\lambda^{H^u} = (1-\beta(1-S)G\delta^u)\lambda^N + \xi + G\delta^u x^a \lambda^{\tilde{L}} + (x^{a,u} - x^a)\lambda^L + ((1-G)x^{a,m} - x^{a,u})\delta^u \lambda^{\tilde{L}}$$

$$C_N = -\frac{\chi}{1+\chi} \frac{H^e \lambda^N + H^u \lambda^{H^u}}{\tilde{N}}.$$

As $\gamma \to \infty$ (i.e. idiosyncratic preferences become unimportant), recruitment and separation elasticities become infinite, and W approaches a weighted average of x^a, $x^{a,u}$ and $x^{a,m}$, while λ^N converges to slightly above 0 (if $\lambda^{H^u} = \lambda^N$), then $\lambda^N \to 0$). As $\gamma \to 0$ (i.e. idiosyncratic preferences entirely determine job choices), recruitment and separation elasticities go to zero, and $W \to 0$. The wage markdown expression differs from the standard $\frac{\varepsilon}{1+\varepsilon}$ because the elasticities are multiplied by $\frac{S}{1-\beta\left(1-\frac{1}{1+\chi}S\right)}$. This is because the elasticity applies only to hires in a given period (S), but firms account for the surplus over the expected lifetime of the match.

We set $\gamma = 100$, so the wage markdown is very small. This helps to generate sufficiently large responses in unemployment, especially in layoffs.[19]

For wage adjustment costs, we need to choose a function $\phi^w(\Pi^w)$. We set ϕ^w to 2500 when nominal wages growth is above $\bar{\Pi}^w = (1/1.005)^(1/12)$ (i.e. 0.5 percent below steady-state inflation) and 20000 when it is below $\bar{\Pi}^w$.

Price setting: We set $\theta = 7.87$ (a standard value in the New Keynesian literature). Price stickiness $\phi^p = 2500$.

Policy: We set $\gamma^p = \frac{1}{48}$, which implies that policymakers place four times as much weight on annualised inflation compared to unemployment in their policy response.

Shocks: The shocks are AR(1) processes with persistence 0.96. The standard deviations are scaled so that the variance of unemployment matches its variance in the data.

A.3 Solution method

The state variables are $\tilde{N}_{t-1}$, W_{t-1}, $\tilde{L}_{t-1}$ and the exogenous shocks A_t and M_t.

We use policy function iteration to solve for the equilibrium. We approximate $\lambda_t^{\tilde{N}}$, $\lambda_t^{\tilde{L}}$, $\Phi_t' \Pi_t$, $\Psi_t \Pi_t^w$ and $E_t^p = \mathbb{E}_t \Phi_{t+1}' \Pi_{t+1} \frac{Y_{t+1}}{Y_t}$ are piecewise linear functions of the state.

Ideally, we would like to choose variables that can be well-approximated as piecewise linear functions of the state. This is why we choose to approximate e.g. $\Psi_t \Pi_t^w$ instead of Π_t^w. Expectations would work

19 Dupraz, Nakamura and Steinsson similarly have only a very small wage markdown. It is well known in the literature that search and matching models can struggle to match unemployment data unless match surplus is very small.

well, because averaging over possible future states 'smoothes out' nonlinearities. The expectations in the model are $\lambda_t^{\tilde{N}}$, $\lambda_t^{\tilde{L}}$ and

$$E_t^p = \mathbb{E}_t \Phi'_{t+1} \Pi_{t+1} \frac{Y_{t+1}}{Y_t}$$
$$E_t^w = \mathbb{E}_t \Psi'_{t+1} \Pi_{t+1}^W \frac{W_{t+1} N_{t+1}}{W_t N_t}.$$

Given values for these variables, all period t variables are determined. But solving the intratemporal equilibrium conditions to get period t variables requires solving a complicated system of nonlinear equations. So we have chosen variables which mostly allow us to solve the intratemporal conditions directly.[20]

Similarly, we could also instead just approximate four variables, which would likely require fewer iterations and could be more accurate. But approximating five makes it easier to solve the intratemporal equilibrium conditions, so each iteration is faster.

20 There is one equation that we cannot solve directly. To avoid using a nonlinear solver within each iteration, we first solve it on a grid before starting the policy function iteration. Then we use this approximate solution in each iteration.

Appendix B: Further results

Table B1: Moments for undetrended Australian and US data

	Model	Aus 1985–2019	US 1990–2019
Unemployment rate			
Standard deviation	1.46	1.79	1.60
Skewness	1.12	0.68	0.88
Skewness of changes	1.37	1.60	2.01
UE rate			
Standard deviation	3.22	2.45	4.25
Skewness	-0.38	0.30	-0.49
Skewness of changes	-0.74	-0.61	-0.40
EU rate			
Standard deviation	0.19	0.25	0.21
Skewness	0.52	0.60	0.13
Skewness of changes	2.02	0.63	0.91

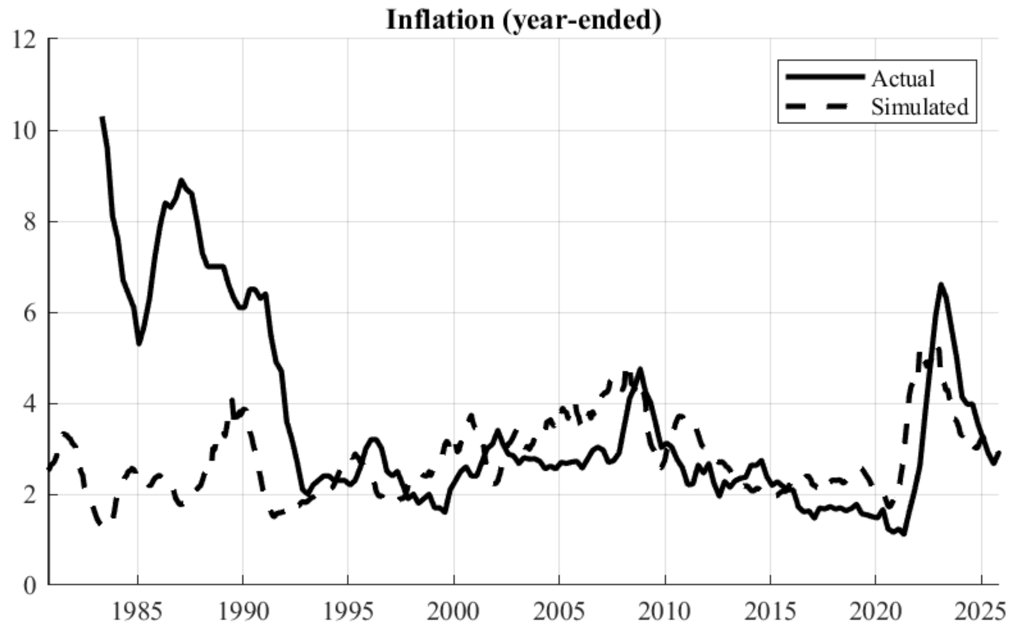
Notes: Data is not detrended. See Table 1 for moments using detrended Australian data.

Table B2: Moments for different versions of model

	Data	Model	Insecurely attached workers + convex recruiting costs	DNWR + convex recruiting costs	DNWR + insecurely attached workers	DNWR	Insecurely attached workers	Convex recruiting costs	None
Unemployment rate									
Standard deviation	1.56	1.44	1.45	1.47	1.46	1.47	1.48	1.49	1.47
Skewness	0.59	1.10	0.87	0.96	1.02	0.92	0.91	0.71	0.66
Skewness of changes	1.71	1.30	1.15	0.25	0.84	0.13	0.73	0.18	0.11
UE rate									
Standard deviation	2.42	3.25	3.78	1.70	5.55	1.77	6.41	2.03	1.97
Skewness	0.40	-0.35	-0.15	-0.60	-0.14	-0.16	-0.02	-0.38	-0.04
Skewness of changes	-0.62	-0.71	-0.65	-0.12	-0.14	0.01	-0.12	-0.07	-0.01
EU rate									
Standard deviation	0.19	0.18	0.19	0.33	0.20	0.35	0.23	0.36	0.39
Skewness	0.57	0.48	0.23	0.81	0.86	0.81	0.72	0.62	0.62
Skewness of changes	0.69	1.97	1.75	-0.07	0.67	0.01	0.60	-0.05	0.02

Notes: The 'Data' column is based on detrended Australian data from 1980 to 2019. The 'Model' column includes all three frictions. The next three columns remove one friction at a time. The next three columns remove two frictions at a time. The last column removes all three frictions.

Figure B1: Labour-market component of inflation



Note: The actual inflation measure is trimmed mean inflation excluded tax and interest changes. The construction of the simulated inflation measure is described in Section 4.

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