Staff memo

Monetary Policy and Procyclical Labour Productivity: A DSGE Model of Labour Hoarding

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Summary

Empirical evidence suggests labour productivity, measured as output per hour worked, responds procyclically to demand shocks, such as monetary policy shocks. However, canonical New Keynesian Dynamic Stochastic General Equilibrium (DSGE) models, which have long served as work-horse models for central banks, struggle to account for the observed pro-cyclicality of labour productivity. Motivated by this disconnect between theory and evidence, we identify a micro-founded mechanism that enables a DSGE framework to replicate the observed procyclical response of labour productivity to monetary policy shocks. We consider labour hoarding serving as a micro-founded mechanism that helps the DSGE framework to account for procyclical labour productivity.

A key limitation of standard DSGE models is that all variations in labour input occur at the extensive margin— employment/hours worked. Consequently, standard DSGE models tend to imply that hours worked move nearly one-for-one with, or even more strongly than, output following a monetary policy shock. Inspired by the work of Sbordone (1996) and Gottfries, Mickelsson and Stadin (2026a), we include the intensive margin of labour input in the form of labour utilisation or effort in addition to the extensive margin. In our context, labour hoarding is viewed as firms being reluctant to adjust employment due to some form of employment adjustment costs. Instead of adjusting their extensive margin, firms prefer to vary the intensive margin of labour input.

Choosing the Riksbank's macroeconomic model MAJA as our baseline DSGE model, we extend the baseline model by incorporating two features, namely employment adjustment costs and variable labour utilisation. Our derived micro-founded labour hoarding condition is captured by the interaction between these two features. The main labour hoarding mechanism is that employment adjustment costs generate sluggish adjustment of employment, creating the gap between desired and actual employment. The resulting gap is in turn absorbed through variations in labour utilisation. In the sense, firms respond to demand by relying mainly on labour utilisation rather than adjusting the extensive margin of labour input.

We first calibrate and subsequently estimate the MAJA model with labour hoarding. The main results are as follows. Firstly, both the calibrated and estimated models generate procyclical labour productivity in response to a monetary policy shock, consistent with the empirical

findings of Christiano, Eichenbaum and Evans (2005), and Qiu and Ríos-Rull (2022). This result reflects the labour hoarding mechanism since the firms prefer to adjust labour utilisation rather than employment. Consequently, the employment response is smaller than in the model without labour hoarding. Hence, hours worked respond less strongly than output (GDP) following the monetary policy shock.

Secondly, both the calibrated and estimated MAJA with labour hoarding models generate a peak labour productivity response that is broadly consistent with our Bayesian Vector Autoregression (BVAR) estimate. Relative to the baseline MAJA model, the labour hoarding extension substantially improves the model's ability to reproduce the empirical peak response of labour productivity identified by the BVAR.

Lastly, closely related to the procyclicality of labour productivity is Okun's law, which captures the empirical relationship between unemployment and GDP. Particularly, an Okun coefficient is measured as the ratio of the peak unemployment response to the peak GDP response. Both models produce Okun coefficients of less than one following a monetary policy shock. The implied Okun coefficients from both models are substantially closer to the empirical estimate reported by Lindgren, Strid and Wang (2026) than that implied by the baseline MAJA model, which generates an Okun coefficient well above the empirical estimate.

The main contribution of this paper is to incorporate labour utilisation and employment adjustment costs into a fully-fledged DSGE model, thereby improving its ability to account for the observed procyclical response of labour productivity and to some extent generating a more realistic unemployment output relationship in response to monetary policy shocks. The proposed labour hoarding condition provides a tractable mechanism through which firms jointly determine extensive and intensive margins of the labour input. Finally, we also examine how different specifications of the labour utilisation cost function affect the optimal labour hoarding condition.

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1 Introduction

Empirical evidence suggests labour productivity, measured as output per hour worked, is procyclical that, rising during expansions, and falling during contractions. However, standard Dynamic Stochastic General Equilibrium (DSGE) models, which have been a workhorse of central banks, struggle to account for the observed procyclicality of labour productivity. In this paper, we focus on how labour productivity responds to demand disturbances, with a particular focus on monetary policy shocks. The main question of this paper is whether we can find a micro-founded mechanism that helps a DSGE model to yield procyclical labour productivity in response to monetary policy shocks.

Structural Vector Autoregression (VAR) studies indicate that labour productivity is procyclical in response to monetary policy shocks. Christiano, Eichenbaum and Evans (2005) show that labour productivity rises after an expansionary monetary policy shock based on a structural VAR using U.S. data. In more recent work, Qiu and Ríos-Rull (2022) also find that labour productivity increases following a decline in the Federal Funds Rate. While previous evidence is based on U.S. data, we apply a Bayesian structural VAR (BVAR) model on Swedish data. Our result confirms their findings that the response of labour productivity is procyclical to monetary policy shocks. In other words, output (GDP) tends to respond more than hours worked following monetary policy shocks.

Other empirical studies document that labour productivity is also procyclical to different types of demand shocks. D'Alessandro, Fella, and Melosi (2019) estimate a BVAR model on U.S. data, and they find that productivity increases, and GDP rises more than hours after a positive government spending shock. Gottfries, Mickelsson and Stadin (2026b) use Swedish firm-level data to construct a firm-specific demand index as a proxy for an exogenous demand shock. They apply a panel VAR model and treat the firm-specific demand index as an exogenous variable, and they find that employment responds more gradually than output to their constructed demand shock.[2]

Closely related to the procyclicality of labour productivity is Okun's law, which captures the empirical relationship between unemployment and GDP. Particularly, an Okun coefficient is measured as the ratio of the peak unemployment response to the peak GDP response. Lindgren, Strid and Wang (2026) find that the cross-country median Okun coefficient is substantial below one conditional on monetary policy shocks. The aforementioned empirical evidence indicates that labour productivity is procyclical, and this also reflected in Okun's law. In other words, output changes more than changes in observed labour input.

[2] Moreover, they find that demand shocks explain most of the medium-term variation in measured TFP and the Solow residual.

However, standard DSGE models can struggle to generate a sufficiently procyclical response of labour productivity to monetary policy shocks.[3] Motivated by this gap between theory and evidence, we incorporate a micro-founded mechanism that enables a standard DSGE framework to generate procyclical labour productivity. Inspired by Sbordone (1996) and Gottfries, Mickelsson and Stadin (2026a), we incorporate a labour hoarding mechanism into a DSGE model, choosing the Riksbank's macroeconomic model MAJA as our baseline model. In our context, labour hoarding refers to firms being reluctant to adjust employment due to employment adjustment costs such as firing, hiring and onboarding costs as well as various forms of employment protection. For example, firms retain more workers than needed in a downturn. Conversely, the opposite occurs in an upturn.

From a technical standpoint, under the baseline MAJA specification, labour input adjusts only along the extensive margin. By construction, the model does not distinguish between employment and hours worked. In this paper, we use employment and hours worked interchangeably since both capture changes in the extensive margin of labour input.[4] A key limitation of the baseline MAJA model as well as other standard DSGE models are that firms typically adjust labour input only via the extensive margin. Consequently, this setup makes it difficult for DSGE models to produce the procyclical response of labour productivity to monetary policy shocks.

We extend the baseline MAJA by incorporating two features which are employment adjustment costs and variable labour utilisation. The introduction of employment adjustment costs makes it costly for firms to adjust employment immediately. By introducing variable labour utilisation, firms now have the option of adjusting the intensive margin in addition to their extensive margin of labour input. Taken together, employment adjustment costs make changes in employment costly, thereby inducing firms to gradually adjust their extensive margin of labour input, generating a gap between desired and actual employment. The resulting gap is accommodated through variations in labour utilisation.

Hence, the interplay between these two features jointly give rise to a labour hoarding mechanism. In addition to employment adjustment costs, firms also face labour utilisation costs; otherwise, firms would always choose the maximum level of effort. The production function is augmented to include labour utilisation, allowing output to vary to some degree independently of the extensive margin of labour input. As a consequence, firms are able to adjust production with a much smaller proportional adjustment in observed labour input, thereby giving rise to procyclical labour productivity.

After embedding the labour hoarding mechanism into MAJA, we first calibrate and subsequently estimate the MAJA model with labour hoarding. The key results from

[3] Standard DSGE models tend to generate countercyclical or acyclical labour productivity.

[4] When comparing the model with the data, however, labour productivity is measured as output per hour worked, and the Okun relationship is evaluated using the response of unemployment rate relative to GDP.

our models with labour hoarding are as follows. First, both the calibrated and estimated models with labour hoarding generate procyclical labour productivity in response to a monetary policy shock. In other words, hours worked respond less strongly than GDP after a monetary policy shock. The intuition is that the labour hoarding introduces an additional firm-side labour input margin which mainly occurs through labour utilisation. Consequently, the employment and hours worked responses are smaller than in the baseline MAJA model. Lastly, the Okun coefficients implied by both calibrated and estimated labour hoarding models are below one, which implies that the peak response of GDP exceeds that of unemployment rate.

Overall, we learn that by incorporating an endogenous labour hoarding into a DSGE model, this improves its ability to capture the observed dynamics of labour productivity and generate a more realistic unemployment to output ratio than the baseline DSGE model without labour hoarding. This brings the model closer to the empirical evidence.

Our theoretical model is closely inspired by Sbordone (1996) who specifies labour adjustment costs and labour utilisation costs as convex cost functions. Moreover, the recent work of Gottfries, Mickelsson and Stadin (2026a) also assume varying utilisation is costly, but they model the utilisation cost in form of organisational capital as their main specification. Specifically, workers can spend time partly on current production and partly productivity-enhancing activities.[5] From that perspective there is a trade-off between increasing current production and future production.[6]

Sbordone (1996) and Gottfries, Mickelsson and Stadin (2026a) develop partial equilibrium models of labour demand. The main contribution of this paper is to extend this literature by embedding a micro-founded labour hoarding mechanism into a fully-fledged New Keynesian DSGE framework, in which the labour hoarding endogenously arises from the interaction between variable labour utilisation and employment frictions. Second, we estimate a DSGE model with labour hoarding using Bayesian methods. Lastly, we also examine the implications of alternative specifications of the labour utilisation cost function.

2 Evidence of procyclical productivity and potential explanations

Empirical evidence shows that labour productivity in Sweden comoves positively with output, implying that labour productivity is procyclical.

[5] Examples of such activities are learning new skills, maintenance, and reorganising.

[6] They build a rich structural model of the firm incorporating multiple adjustment margins, namely increasing returns, factor utilisation, inventories, adjustment costs of factor of production, and implementation lags of factor of production. They argue that by allowing firms to respond more flexibly to changes in demand, this substantially reduces the role of exogenous technology shocks for explaining output fluctuations.

Having established the empirical regularity, we then turn to a BVAR model to quantify the effects of monetary policy shocks on labour productivity. Our BVAR result reveals that labour productivity is highly procyclical. Specifically, the peak response of labour productivity is economically significant as well as is highly persistent.

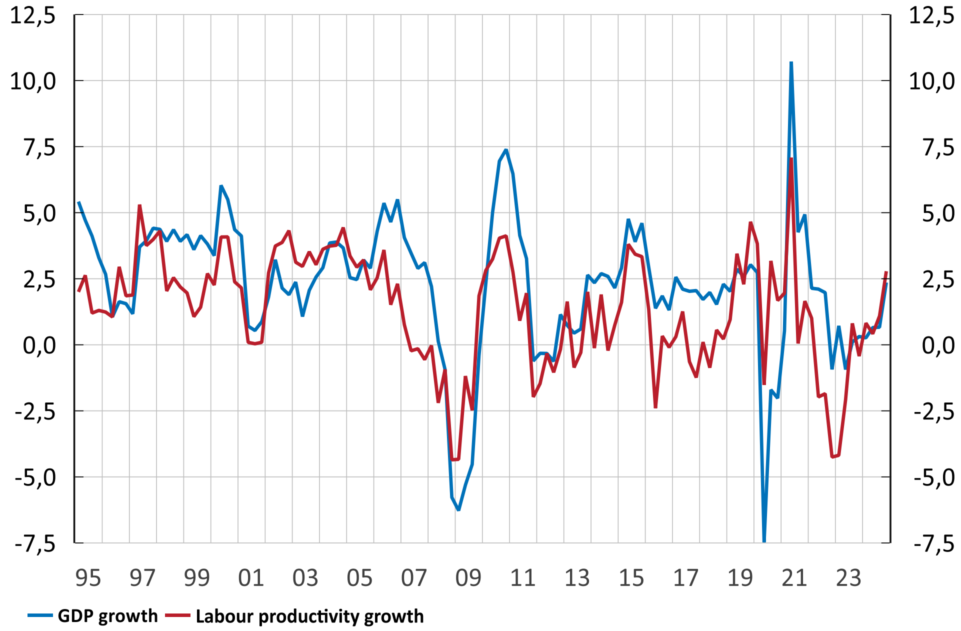
Most of existing DSGE models incorporate features such as increasing returns to scale and capital utilisation to help to describe procyclical productivity. However, these features can explain only a small portion of procyclical productivity. Gottfries, Mickelsson and Stadin (2026b) argue that factor utilisation, particularly labour utilisation, is important for understanding the cyclical behaviour of labour productivity.

2.1 Stylised facts: procyclicality of labour productivity

Figure 1 shows the relationship between Sweden's GDP and labour productivity growth. The data covers the period 1995Q1–2025Q4. The figure indicates that there is positive co-movement between GDP growth and labour productivity growth. In fact, the correlation between these two variables is around 0.68. Sweden's labour productivity typically declines during economic downturns, and productivity tends to rise during expansions. Additionally, GDP appears to be more volatile than labour productivity.

Figure 1. GDP and labour productivity

Annual percentage change



Note: The Y-axis shows GDP and labour productivity as annual percentage changes. The X-axis shows year. The blue line represents GDP growth, and the red line represents labour productivity growth. GDP is measured at market prices and seasonally adjusted. Labour productivity is defined as the ratio GDP to total hours worked.

For the empirical regularity of U.S. labour productivity, see Hart and Malley (1999), Baily, Bartelsman and Haltiwanger (2001), Basu and Fernald (2001), and Field (2010). Moreover, Dossche, Gazzani and Lewis (2023) document that labour productivity is generally procyclical across OECD countries, and countries with lower employment volatility tend to exhibit stronger procyclicality in labour productivity.

A related concept of procyclical labour productivity is Okun's law, which captures the empirical relationship between GDP and unemployment. The Okun coefficient measures the percentage change in the unemployment rate associated with a one percent change in GDP. Lindgren, Strid and Wang (2026) estimate the monetary policy-conditional Okun coefficient as the ratio of the peak responses of the unemployment rate and real GDP for 10 different small open economies. They find that estimated Okun coefficient for Sweden is about 0.6, which is also close to the cross-country median.

2.2 Empirical evidence from BVAR

In this section, we apply a Bayesian VAR (BVAR) model to analyse the effects of monetary policy shocks on labour productivity using Swedish data. In our BVAR model, we have quarterly data for four Swedish variables and three foreign variables. The Swedish variables are the log labour productivity, annual year-over-year (YoY) CPIF inflation, the policy rate in level, and the log real exchange rate. The foreign variables are KIX-weighted measures of log GDP, annual year-over-year (YoY) CPI inflation and the policy rate in level.[7] The sample covers the period 1995Q2–2024Q4.

We estimate the model with Bayesian methods, and our estimation strategy is inspired by the work of Berggren, Mammos and Strid (2024). We adopt priors broadly similar to those used in their paper. We treat foreign variables as exogenous regressors and unaffected by developments in the Swedish economy, approximating the small open economy assumption.[8] Identification is achieved via a recursive (Cholesky) decomposition, and monetary policy shocks are identified from innovations in the policy rate.[9] Particularly, the ordering of variables follows the standard practice in VAR analysis that is slow-moving variables are ordered before faster-moving variables: [labour productivity, inflation rate, policy rate, real exchange rate]. This implies that labour productivity and inflation do not respond contemporaneously, whereas the real exchange rate responds instantaneously to unexpected monetary policy shocks.

[7] KIX (krona index) is a trade-weighted index, where the weights are based on Sweden's trade shares across 31 countries.

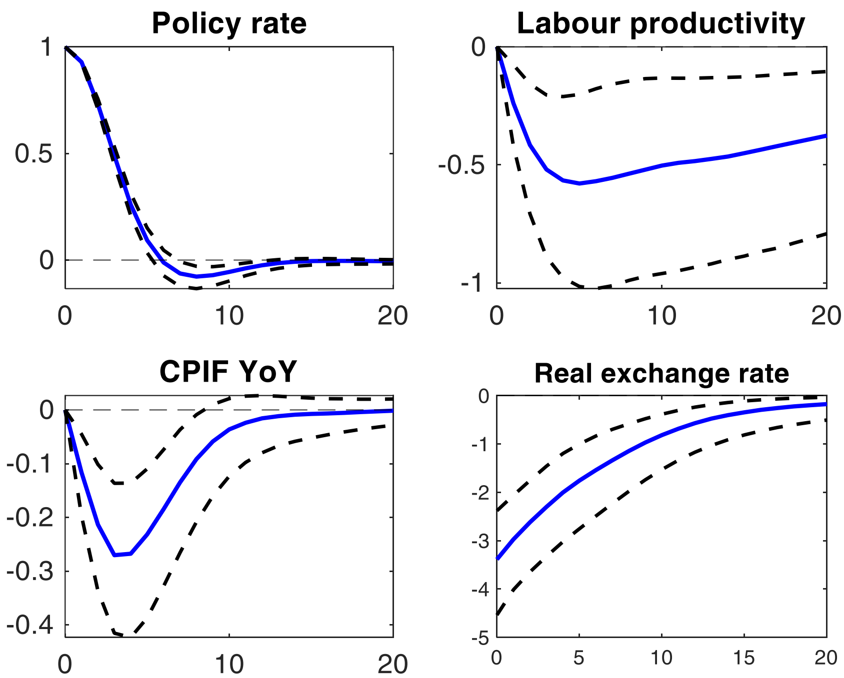
[8] Berggren, Mammos and Strid (2024) model foreign variables jointly with Swedish variables, while imposing that Swedish developments do not affect the foreign variables. In contrast, we treat foreign variables as exogenous regressors by taking them as given. Both approaches reflect the small open economy assumption that foreign developments affect Sweden, but not vice versa.

[9] For more technical details, please see Appendix B and Berggren, Mammos and Strid (2024).

Figure 2 displays impulse response functions to a monetary policy shock, scaled to a one percentage point increase in the policy rate. A contractionary monetary policy shock leads to an economically and statistically significant decline in labour productivity given probability intervals of size 90 per cent. The peak effect of labour productivity is about 0.56 percent, and the response of labour productivity is quite persistent. A decline in the real exchange rate denotes a real appreciation of the Swedish krona. The response of CPIF inflation and real exchange rate are broadly consistent with Berggren, Mammos and Strid (2024), particularly inflation rate declines while the real exchange rate appreciates.[10]

Our BVAR result also confirm the finding by Christiano, Eichenbaum and Evans (2005) and Qiu and Ríos-Rull (2022) that is labour productivity is procyclical responding to monetary policy shocks.

Figure 2. BVAR: Impulse responses to a monetary policy shock



Note. The figure shows the effects of a monetary policy shock in the baseline model, scaled to a one-percentage-point increase in the policy rate. The model is estimated on data for the period 1995Q1-2024Q4. The CPIF is shown in annual percentage change and other variables in level. The black lines show probability intervals of 90 per cent and the blue line shows the median response.

[10] For a robustness check, we control for the COVID-19 period by including a dummy variable (2020Q1 to 2021Q4) in the BVAR. The quantitative results are similar, see Appendix B.

2.3 Potential explanations for procyclical productivity

Empirical evidence suggests that firms are able to adjust production with a much smaller percentage change in observed factor inputs, namely physical capital and employment/hours, following a change in demand, for example a monetary policy shock.

Based on the empirical evidence, Hall (1988) argues that increasing returns to scale explain procyclical productivity. Increasing returns to scale arise from fixed costs. This implies that under monopolistic competition, firms charge a markup over marginal cost to cover fixed costs, thereby ensuring zero profits in equilibrium. Given increasing returns to scale, output responds more than proportionally to factor inputs. As a result, labour productivity can be procyclical. However, his study reports a relatively high markup over marginal cost. Therefore, for this mechanism alone to generate sufficiently strong procyclical productivity, this would require a very large markup over marginal cost, which are empirically difficult to justify.

One mechanism that partly alleviates this problem is capital utilisation in which Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2007) incorporate into a DSGE framework. Capital utilisation allows firms to vary the intensive use of physical capital rather than adjusting physical capital directly. However, this feature only marginally improves the models' ability to match procyclical productivity in response to monetary policy shocks. In general, most DSGE models already incorporate both increasing returns to scale and capital utilisation (see Christiano, Trabandt, and Walentin 2010). However, these two features can explain only a small portion of procyclical productivity.

A key limitation of standard DSGE models is that firms typically adjust labour input only through the extensive margin, namely employment. This inflexibility of firms' adjustment margins implies that labour input tends to move proportionally with output. As a result, labour productivity exhibits little cyclical variation. Hence, standard DSGE models struggle to generate sufficiently procyclical labour productivity despite incorporating increasing returns to scale and capital utilisation. The same limitation applies to the baseline MAJA, where all variations in the labour input occur through the extensive margin.

Basu and Fernald (2001), Basu, Fernald and Kimball (2006), Fernald and Wang (2016), and Gottfries, Mickelsson and Stadin (2026b) argue that factor utilisation, particularly labour utilisation is important for understanding cyclical productivity movements. Motivated by the empirical evidence on the procyclicality of productivity and the role of labour utilisation, we therefore incorporate labour utilisation as an additional margin of labour input, which helps the DSGE model to account for procyclical labour productivity.

3 Theoretical framework

In this section, we modify the standard firm's decision problem by incorporating labour utilisation and employment adjustment costs. First, we augment the standard production function with labour utilisation. Second, we model employment adjustment and labour utilisation costs as convex cost functions. Third, we derive firms' labour demand decisions along both the extensive margin and the intensive margin. Fourth, we derive the optimal labour hoarding condition.

3.1 Labour utilisation and employment adjustment costs

In this section, we show how to integrate a labour hoarding mechanism into a DSGE model.[11] In particular, we modify the intermediate firm's cost-minimisation problem by incorporating variable labour utilisation and employment adjustment costs into the baseline MAJA model. For expositional clarity, we abstract from other features of the firm's block and focus on the firm's labour input decisions. Specifically, we derive labour demand along both the extensive margin and the intensive margin.[12]

A representative firm employs labour input (number of workers) N_t and capital services K_t to produce output Y_t. The firm takes the nominal wage W_t, and the rental rate of capital services R_t^K as given. In our framework, there is no explicit distinction between hours worked and the number of workers; both are captured by the same labour variable N_t.

The first modification is that we allow the firm to choose the level of labour utilisation or effort ef_t as an additional choice variable.[13] Labour utilisation is therefore interpreted as a firm side intensive margin. Labour utilisation reflects how intensively the firm utilises existing workers, for example, managers require greater work intensity or reduce idle time, changes in work organisation or a reallocation of workers' time toward productive activities. Accordingly, the effective labour input consists of observed labour input N_t, which captures variations in the extensive margin, and labour utilisation ef_t captures variations in the intensive margin of the labour input which is an unobserved variable. In our setting, labour utilisation directly affects the effective labour input but does not directly affect the household labour disutility.[14] We have the following production function:

[11] We focus on the Riksbank's macroeconomic model MAJA, which is an estimated DSGE model for Sweden and its main trading partners, the euro area and the United States.

[12] The full specification of the baseline MAJA model can be found in Corbo and Strid (2020).

[13] We use labour utilisation and effort interchangeably in this paper.

[14] For an alternative approach in which labour effort is modelled as a household-side labour supply decision; see Burnside, Eichenbaum and Rebelo (1993), Burnside and Eichenbaum (1996), and Dossche, Gazzani and Lewis (2023).

$$Y_t = (ef_t N_t)^{1-\alpha} \epsilon_t K_t^{\alpha}, \quad (1)$$

where ϵ_t is a temporary technology shock. Eq. (1) implies that when the firm chooses a higher level of labour utilisation, this directly raises the level of output. However, the firm incurs costs when varying labour utilisation. Examples of these costs associated with labour utilisation, are such as managerial supervision, monitoring, and organisational costs, which are entirely born by the firm.

The labour utilisation cost $\phi(ef_t)$ is specified as a convex cost function. The steady state of labour utilisation is normalised to 1, $ef = 1$, accordingly the cost function has the following properties: $\phi(1) = 0$, $\phi'(1) > 0$, and $\phi''(1) > 0$. These assumptions imply that the cost of utilisation is zero at the normal level of labour utilisation, while any deviation of labour utilisation from its steady state level entails a positive and increasing marginal cost.

Analogous to the standard functional form of the capital utilisation in the DSGE literature, one possible functional form for the labour utilisation cost can be stipulated as:

$$\phi(ef_t) = \frac{\gamma_u \varphi_u}{2} {ef_t}^2 + \gamma_u (1 - \varphi_u) ef_t + \gamma_u \left(\frac{\varphi_u}{2} - 1\right). \quad (2)$$

The ratio $\phi''(1)/\phi'(1)$ determines the curvature of the cost function and is denoted by φ_u, labour utilisation cost parameter.[15] A higher value of φ_u implies that it becomes more costly for the firm to adjust labour utilisation; consequently, the firm has less incentive to adjust effort. Moreover, in this benchmark specification, the labour utilisation cost function is assumed not to be indexed to wages.[16]

The second modification to the firm's problem is that we introduce employment adjustment costs to capture a sluggish adjustment of labour input along the extensive margin. We adopt a following standard quadratic employment adjustment cost, similar to the convex benchmark considered by Cooper and Willis (2009) and drawing on Lechthaler and Snower (2013):

$$\Psi(N_t) = \frac{\varphi_n}{2} \left(\frac{N_t}{N_{t-1}} - 1\right)^2 N_{t-1}, \quad (3)$$

where $\Psi(N_t)$ denotes the employment adjustment cost of changing the extensive margin of labour input incurred by the firm, and φ_n captures the employment adjustment cost parameter.[17] This quadratic functional form implies a convex adjustment cost; hence, the employment adjustment costs rise with the employment growth relative to the firm's existing employment. A higher value of φ_n signifies that

[15] $\gamma_u > 0$ captures the marginal cost of labour utilisation at its normal (steady state) level, thus φ_u determines how fast the marginal cost rises as labour utilisation deviates from its normal level.

[16] Section 5 considers an alternative specification of labour utilisation cost function that varies with wages.

[17] This quadratic adjustment cost in employment growth is analogous to an investment adjustment cost in the DSGE literature.

it becomes more costly for the firm to adjust the extensive margin of labour input for a given change in the firm's employment level.

Given the production and labour utilisation cost and employment adjustment cost functions, we can derive the marginal product of labour and marginal of capital.[18]

$$MPL_t = (1-\alpha)(ef_t)^{1-\alpha}\epsilon_t\left(\frac{K_t}{N_t}\right)^{\alpha}, \tag{4}$$

and

$$MPK_t = \alpha(ef_t)^{1-\alpha}\epsilon_t\left(\frac{K_t}{N_t}\right)^{-(1-\alpha)}. \tag{5}$$

Eq. (4) shows the expression for marginal product of labour MPL_t which is determined by capital to labour ratio (K_t/N_t), and labour utilisation ef_t. Higher labour effort directly raises the marginal product of labour. Eq. (5) represents the marginal product of capital MPK_t depends on the capital to labour ratio and labour utilisation. An increase in labour utilisation also directly raises the marginal product of capital.

3.2 Extensive and intensive labour decisions

In this section, we derive firms' labour demand decisions along two margins: the extensive margin through observed labour input N_t , and the intensive margin through labour utilisation ef_t.[19]

The representative firm minimises total production costs by choosing the extensive part of labour input N_t, the intensive part of labour input ef_t, and capital services K_t subject to the production technology, and the demand schedule for its goods. In addition to standard wage and capital rental costs, the firm faces both convex labour utilisation costs and employment adjustment costs.[20] We can derive the following optimal firm's decision for the extensive margin of labour input, the intensive margin of labour input and capital services:

$$MC_t = \frac{W_t+\phi(ef_t)+\varphi_n\left(\frac{N_t}{N_{t-1}}-1\right)-\beta E_t\left[\varphi_n\left(\frac{N_{t+1}}{N_t}-1\right)\right]}{MPL_t}, \tag{6}$$

$$MC_tMPL_t = \phi'(ef_t)ef_t, \tag{7}$$

and

$$R_t^K = MC_tMPK_t. \tag{8}$$

[18] We denote the hatted variables as log-deviations from the steady state.

[19] The Appendix contains the derivation of the first-order conditions and the log-linearisation of the model.

[20] To preserve tractability under Calvo pricing, labour demand decisions can be undertaken by a representative labour aggregator which supply homogeneous labour services to the representative firm. This avoids introducing firm-specific employment as an additional state variable.

Eq. (6) represents the firm's optimal labour demand condition in which the extensive labour input N_t is determined by the marginal cost of production MC_t, the nominal wage W_t , the marginal product of labour MPL_t plus the dynamic marginal employment adjustment cost expression as well as the labour utilisation cost $\phi(ef_t)$.[21] A higher wage increases the marginal cost which induces the firm to reduce the demand for labour input along the extensive margin. In contrast, a higher marginal product of labour induces the firm to increase labour input along the extensive margin.

The dynamic marginal employment adjustment cost expression consists of the current marginal cost $\varphi_n\left(\frac{N_t}{N_{t-1}}-1\right)$, and the discounted expected future marginal adjustment cost $\beta E_t\left[\varphi_n\left(\frac{N_{t+1}}{N_t}-1\right)\right]$. Intuitively, if the firm expects future employment growth to be positive, the firm can reduce the need for large future hiring and save employment adjustment costs by hiring more today. If the current employment growth is high, the firm can reduce the current employment adjustment costs by postponing part of its hiring to future periods. Thus, the firm seeks to smooth hiring over time rather than making a large one-period employment adjustment. In other words, the firm weighs between the current and expected future marginal adjustment costs; thereby giving rise to an intertemporal labour demand condition.

As mentioned earlier φ_n governs the degree of employment adjustment costs, if $\varphi_n = 0$, the labour demand condition collapses to the static and standard's labour demand condition. If $\varphi_n > 0$, this introduces employment frictions; consequently, the labour demand condition becomes forward-looking. As the labour utilisation costs $\phi(ef_t)$ enters the nonlinear labour demand equation, variations in the labour utilisation directly affects the marginal cost of production and ultimately affects inflation dynamics.

Eq. (7) shows the optimal labour utilisation condition which is not presence in a standard DSGE framework. The firm chooses labour utilisation ef_t such that the marginal benefit of varying labour utilisation MC_tMPL_t equals its marginal cost or the shadow cost $\phi'(ef_t)ef_t$.[22]

Given that $\phi'(ef_t) = \gamma_u\varphi_u ef_t + \gamma_u(1-\varphi_u)$ and $\phi''(1)/\phi'(1) = \varphi_u$, the labour utilisation cost parameter φ_u determines the responsiveness of labour utilisation to changes in the macroeconomic variables. A higher value of φ_u implies it becomes more costly to vary labour utilisation, and as a result the firm relies less on the intensive margin of labour input. As φ_u approaches very large values, the labour utilisation becomes non-responsive to macroeconomic shocks. Conversely, as φ_u approaches zero, it becomes more flexible to vary labour utilisation.

[21]Our firm's labour demand condition differs from the standard formulation because of the presence of employment adjustment costs. The standard firm's optimal labour demand condition is simply the marginal cost equals the real wage relative to the marginal product of labour.

[22] The labour utilisation costs affect the labour market equilibrium through the firm's optimal labour demand and labour utilisation decisions. These costs capture shadow costs associated with adjusting the intensity of labour input rather than a use of real resources; hence, they do not enter the aggregate resource constraint.

Lastly, Eq. (8) captures the rental rate of capital R_t^K which is determined by the marginal cost and the marginal product of capital. The firm's labour demand and labour utilisation decisions jointly underpin the labour hoarding mechanism which is discussed next.

In the MAJA model, unemployment is modelled through the labour force participation constraint as in Galí, Smets and Wouters (2012), rather than through a search-and-matching framework. Employment therefore represents the extensive margin of labour input, and unemployment reflects the gap between the labour force and employment.

3.3 Labour hoarding condition

This section shows how the labour hoarding emerges from the interaction between flexible labour utilisation and employment adjustment frictions. By combining Eq. (6) and Eq. (7), we can derive the benchmark labour hoarding condition. For expositional purposes, we show the associated log-linear equation:

$$\widehat{ef}_t = \frac{1}{\varphi_u}\left[\widehat{w}_t + \frac{\varphi_n}{W}\left[(\widehat{N}_t - \widehat{N}_{t-1}) \; - \; \beta E_t\,(\widehat{N}_{t+1} - \widehat{N}_t)\right]\right], \tag{9}$$

where φ_u is the labour utilisation cost parameter, and φ_n is the employment adjustment cost parameter. We denote $\widehat{w}_t$ as the log-linear deviation of the real wage from its steady state, and $\widehat{N}_t$ represents the log-linear deviation of employment from its steady state.[23] Eq. (9) represents the labour hoarding condition which is determined by the real wage and the dynamic marginal employment adjustment cost term $\frac{\varphi_n}{W}\left[(\widehat{N}_t - \widehat{N}_{t-1}) \; - \; \beta E_t\,(\widehat{N}_{t+1} - \widehat{N}_t)\right]$ given the magnitude of labour utilisation cost parameter φ_u.

Ceteris paribus, a higher real wage raises the cost of labour along the extensive margin; therefore, firms rely more on the intensive margin—labour utilisation. The dynamic marginal employment adjustment cost term introduces a delayed adjustment of employment. Particularly, employment adjustment frictions create the gap between desired and actual employment. Ceteris paribus, higher employment adjustment costs induce firms to change employment gradually; consequently, the firms absorb the resulting gap by adjusting labour utilisation.

Given that the benchmark labour utilisation cost function is independent of wages as shown by Eq. (2), the benchmark labour hoarding condition depends on the real wage. The intuition is that changes in the real wage alter the cost of using the extensive margin relative to the intensive margin of labour input. Consequently, firms choose between employing additional workers and labour utilisation. In Section 5, we

[23] A hatted variable denotes log deviations from the steady state.

show the implications of an alternative specification of labour utilisation cost function that varies with wages for the labour hoarding condition.

4 MAJA model with labour hoarding: impulse response functions

We first calibrate and subsequently estimate the MAJA model with labour hoarding. Both the calibrated and estimated models with labour hoarding generate procyclical labour productivity in response to a monetary policy shock, consistent with the empirical findings of Christiano, Eichenbaum and Evans (2005), and Qiu and Ríos-Rull (2022). Moreover, the peak responses of labour productivity in both calibrated and estimated models are in line with our BVAR estimate. The Okun coefficients implied by both calibrated and estimated labour hoarding models are below one which is in line with Lindgren, Strid and Wang (2026).

Both the calibration and estimation exercises assess whether the labour hoarding mechanism helps the DSGE model to capture key features of the empirical evidence, rather than to provide a fully independent validation of the mechanism. Overall, by incorporating labour hoarding, this substantially improves the dynamics of labour productivity and unemployment to output ratio relative to the model that exclude labour hoarding, thereby bridging the gap between the theoretical framework and empirical evidence.

4.1 Calibration

In this section, we calibrate the MAJA model with labour hoarding. The calibration has two objectives. The primary objective is that the model can generate a procyclical labour productivity response to a monetary policy shock, which constitutes the central empirical motivation for introducing labour hoarding into a DSGE framework. The secondary objective is for the model to generate an Okun coefficient, measured as the peak unemployment to output ratio, to be less than one. The goal of this section is intended to assess whether the labour hoarding mechanism can discipline the DSGE model to match the empirical evidence, and the results should not be interpreted that this mechanism is the sole explanation for the empirical regularities. We now discuss the calibration procedure in more detail.

The MAJA model with labour hoarding is calibrated to broadly match the peak response of labour productivity to a contractionary monetary policy shock observed in the BVAR presented in Section 2. In particular, the BVAR is used to discipline the calibration of the parameters associated with the labour hoarding mechanism, namely the labour utilisation cost and the employment adjustment cost. The calibration also aims to yield a Okun coefficient close to the empirical estimate for Sweden reported by Lindgren, Strid and Wang (2026).

Specifically, the labour utilisation cost parameter φ_u is calibrated to a relatively low value since this allows firms to adjust labour utilisation flexibly in response to economic fluctuations. In contrast, the employment adjustment cost parameter φ_n is calibrated to a relatively high value to capture the sluggishness of employment dynamics. Table 1 reports the calibrated values of these labour hoarding parameters. All remaining structural parameters are kept at their baseline MAJA model's values.[24]

Table 1. Calibrated parameter values for the labour hoarding mechanism

Parameter	Description	Value
φ_u	Labour utilisation cost	0.1
φ_n	Employment adjustment cost	30

Table 2 reports the calibration targets and the corresponding model implied values. The labour hoarding extension substantially improves the fit of the model relative to the baseline specification. Overall, it generates a procyclical labour productivity response reasonably close to the BVAR estimate and considerably reduces the implied Okun coefficient, thereby bringing the model closer to the empirical evidence.

Firstly, given the calibrated parameter values, the MAJA model with labour hoarding generates a peak labour productivity response of 0.68, compared with the BVAR estimate of approximately 0.56. The model with labour hoarding also provides a substantially better match to the empirical evidence than the baseline MAJA model, which generates a peak response of labour productivity that is nearly flat.[25]

Secondly, the calibration of the model with labour hoarding also produces a Okun coefficient of about 0.94, it remains somewhat higher than the calibration target. Nevertheless, it is substantially lower than 1.67 implied by the baseline MAJA model and considerably closer to the empirical estimate of about 0.60 reported by Lindgren, Strid and Wang (2026).

[24] The complete set of baseline parameter values is reported in Appendix Table C1 and C2.

[25] Moreover, the MAJA model with labour hoarding implied response remains well within the BVAR credible interval.

Table 2. Calibration targets and model implied values

Empirical Estimate	Calibration target	Baseline MAJA	MAJA with labour hoarding
Peak labour productivity response	0.56	0.04	0.68
Okun coefficient	0.60	1.67	0.94

Note: The calibration targets are obtained from two empirical sources. The peak labour productivity response is taken from the BVAR estimate presented in Section 2, while the Okun coefficient is taken from Lindgren, Strid and Wang (2026). The Okun coefficient is defined as the ratio of the peak unemployment response to the peak output response following a contractionary monetary policy shock.

To sum-up, the labour utilisation and employment adjustment cost parameters are calibrated partly to match the procyclical labour productivity which represents the main empirical benchmark as well as the Okun coefficient which serves as a secondary empirical benchmark. As mentioned in Section 2, the labour hoarding is one of the explanations for this empirical evidence, but the main goal of this paper is to highlight the labour hoarding mechanism. In Section 6, we briefly discuss how to further improve the model's ability to match the empirical facts.

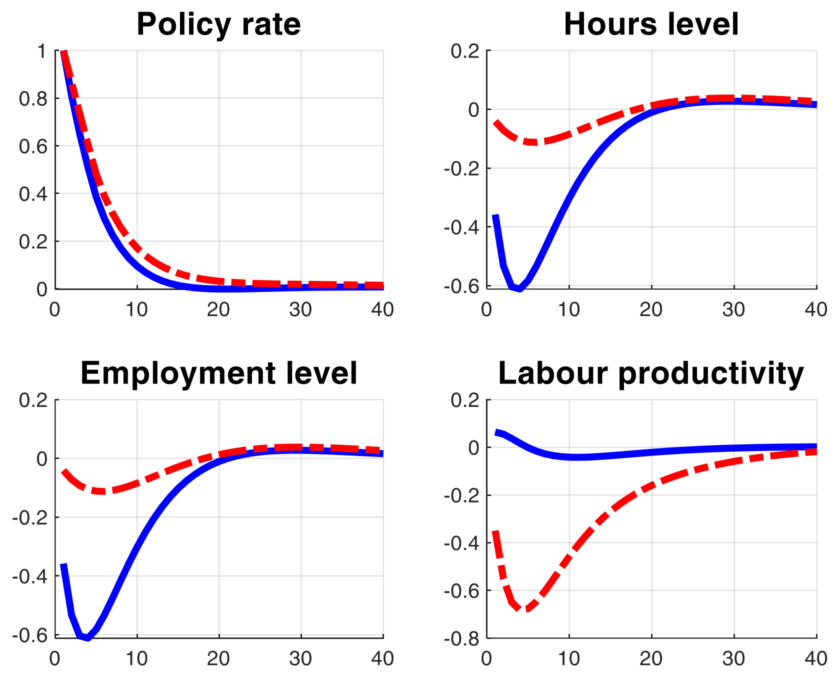
4.2 Impulse responses of the calibrated labour hoarding model

We examine the implications of the labour hoarding mechanism by comparing the impulse responses of labour productivity as well as other key macroeconomic variables to a contractionary monetary policy shock in the baseline MAJA model, and the calibrated version of MAJA with the labour hoarding. The aim of this section is to provide intuition for the implications of incorporating labour utilisation and employment adjustment frictions by examining the models' impulse responses.

Figure 3A-3C show the impulse response functions to the contractionary monetary policy shock. The blue line represents the baseline MAJA model, and the red line represents the calibrated labour hoarding model. To facilitate the comparisons, the impulse responses of the policy rate from both models are normalised to one percentage point.

Firstly, we inspect the responses of the extensive margin of labour input, namely employment and hours. According to Figure 3A, the responses of employment and hours are substantially more attenuated under the model with labour hoarding than under the baseline model. In the baseline model, labour productivity increases slightly, and it subsequently displays acyclical behaviour. By comparison, in the labour hoarding model, labour productivity decreases. Moreover, the peak response of labour productivity is substantially closer to that observed in the data than that of the baseline model.

Figure 3A. Impulse responses to a contractionary monetary policy shock: baseline and calibrated labour hoarding model



Note. The figure shows the effects of a contractionary monetary policy shock on key macroeconomic variables, and the responses of policy rate are normalised to one percentage point. The blue line represents the baseline MAJA, and the red line represents the calibrated labour hoarding model. The CPIF is shown in annual percentage change and other variables in level.

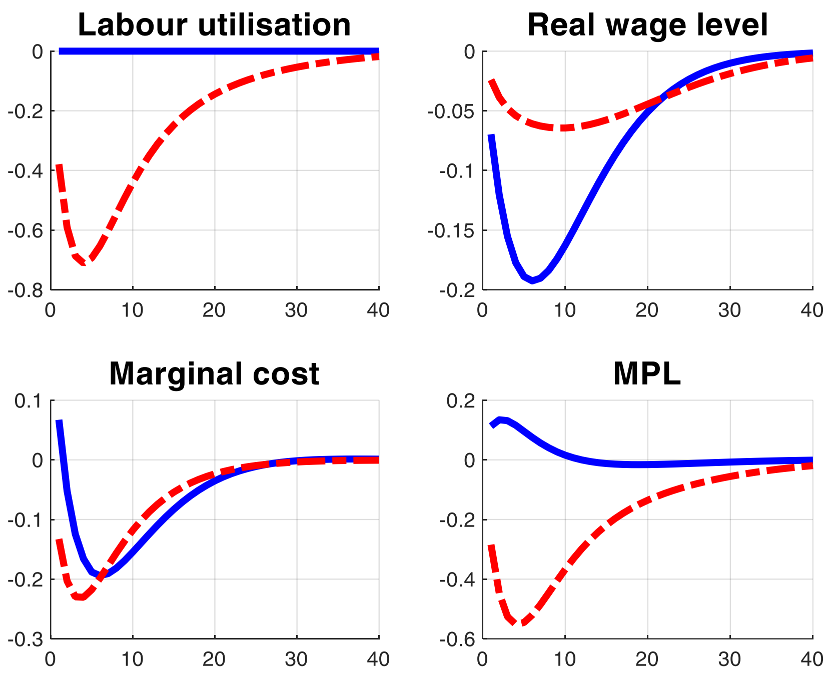
Secondly, we examine the responses of variables that are directly connected to the optimal labour hoarding condition. i.e. Eq. (9). The labour hoarding model generates a smaller employment response than the baseline model because a substantial part of the adjustment occurs through labour utilisation. Figure 3B illustrates the intuition behind the labour hoarding mechanism. In particular, it shows how a range of macro-factors drive the response of labour utilisation.

Following the contractionary monetary policy shock, aggregate demand declines, and this effect leads to a reduction in labour demand; as a result the real wage declines. According to the labour hoarding condition, a decline in the real wage induces firms to rely less on labour utilisation. Intuitively, a fall in the real wage reduces the cost of using labour along the extensive margin relative to the intensive margin. This encourages firms to substitute away from the intensive margin toward the extensive margin of labour input. As a result, labour utilisation declines following a fall in the real wage.

According to the labour hoarding condition, labour utilisation is also affected by the dynamic employment adjustment cost term. Given our relatively high calibration of employment adjustment cost parameter, labour utilisation is more responsive than employment to the monetary policy shock. Intuitively, employment frictions induce the firms to change employment gradually; consequently, the firms absorb the gap between desired and actual employment by varying labour utilisation.

Overall, the response of employment, labour utilisation, real wage, marginal product of labour, and real marginal cost are negative to the contractionary monetary policy shock. These results are in line with our economic intuition.

Figure 3B. Impulse responses to a contractionary monetary policy shock: baseline and calibrated labour hoarding model



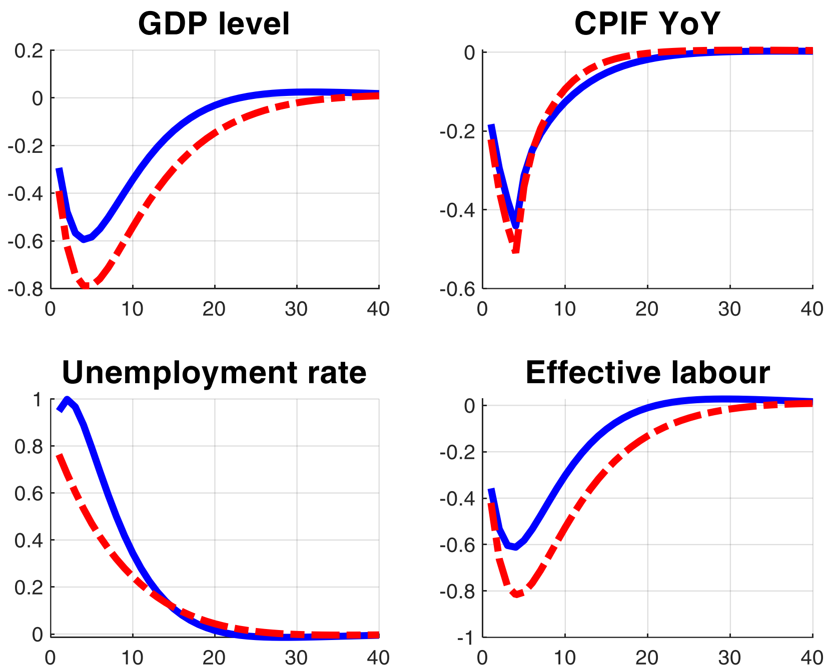
Note. The figure shows the effects of a contractionary monetary policy shock on key macroeconomic variables, and the responses of policy rate are normalised to one percentage point. The blue line represents the baseline MAJA, and the red line represents the calibrated labour hoarding model. The CPIF is shown in annual percentage change and other variables in level.

Thirdly, we turn to the responses of other macroeconomic variables as shown in Figure 3C. Labour hoarding has an indirect effect on the response of unemployment rate. In the labour hoarding model, the peak response of unemployment rate is attenuated relative to the baseline model, because the firms hoard workers despite the decline in aggregate demand. In the baseline model, the response of effective labour input equals the response of the extensive margin of labour input. In the labour hoarding model, the effective labour input is determined by both the extensive margin of labour input and labour utilisation. As a result, the effective labour input falls more in the labour hoarding model than that of the baseline model. Moreover, in the labour hoarding model, GDP declines more than that of the baseline model.

Additionally, compared with the baseline MAJA model, the MAJA model with labour hoarding generates a larger decline in GDP and a smaller increase in the unemployment rate. Consequently, the labour hoarding mechanism contributes to generating an implied Okun coefficient slightly below one, whereas the baseline MAJA model produces an Okun coefficient substantially above one. Lastly, the response of inflation (CPIF) is negative in both models.

To sum-up, the model with labour hoarding can generate procyclical labour productivity. The main reason is that the labour hoarding mechanism breaks an almost one-to-one relationship between GDP and hours. Taken together, our model with labour hoarding shows a substantial improvement over the baseline model regarding matching labour productivity and unemployment to output ratio.

Figure 3C. Impulse responses to a contractionary monetary policy shock: baseline and calibrated labour hoarding model



Note. The figure shows the effects of a contractionary monetary policy shock on key macroeconomic variables, and the responses of policy rate are normalised to one percentage point. The blue line represents the baseline MAJA, and the red line represents the calibrated labour hoarding model. The CPIF is shown in annual percentage change and other variables in level.

4.3 Bayesian estimation

The MAJA model with labour hoarding is estimated using Bayesian methods with data for Sweden, the euro area and the United States. The model is estimated on data for the period 1995Q2-2024Q4. The estimation strategy is designed to isolate the incremental contribution of the labour hoarding mechanism rather than fully re-estimate all structural parameters. Hence, we set the structural parameters that relevant to monetary policy transmission equal to the posterior estimates of the baseline MAJA model, as a result this enables the data to identify the newly introduced labour hoarding mechanism.

Specifically, the structural parameters governing household behaviour, nominal rigidities, the monetary policy rule, the UIP condition, and capital utilisation are fixed at the posterior estimates from the baseline model and are therefore not re-estimated in the Bayesian estimation of the labour hoarding model (see Appendix Table D1). Fixing them ensures that any changes in the impulse responses to monetary policy shocks can be primarily attributed to the introduction of labour hoarding rather than simultaneous changes in unrelated structural parameters. The remaining model parameters such as the foreign structural parameters and the stochastic shock processes are estimated jointly with the labour hoarding parameters using Bayesian methods.[26] Appendix Table D2 reports the prior means together with the posterior modes for both the baseline MAJA model and the estimated MAJA with labour hoarding model.[27]

We focus on parameters that are central to the model extension: labour utilisation cost φ_u, and employment adjustment cost φ_n. As in the calibration exercise, the estimation exercise is guided by two empirical observations. The primary objective is to specify the prior mean of these two parameters such that the estimated labour hoarding model can generate the peak response of labour productivity to a monetary policy shock that is consistent with the BVAR evidence presented in Section 2. Additionally, the Okun ratio is used as a secondary empirical benchmark with the aim of the estimated labour hoarding model can also generate a more realistic Okun ratio relative to the baseline model.

The Bayesian estimation combines prior information with the observed data to quantify the strength of the labour hoarding mechanism. Table 3 reports prior and posterior estimates of the labour hoarding parameters. Particularly, we assume labour utilisation is relatively flexible, thereby suggesting a low prior mean for the labour utilisation cost parameter φ_u. On the other hand, a prior mean for the employment adjustment cost parameter φ_n is assumed to be high to capture the sluggishness of employment dynamics. The prior standard deviations for $\varphi_u$and φ_n suggest relatively informative priors. The labour utilisation cost parameter and employment adjustment cost parameter are assigned a gamma distribution to ensure positivity, and the parameters remain within economically meaningful bounds. The gamma distribution has been applied in different DSGE model parameters such as the capital utilisation parameter, the investment adjustment cost parameter, and the labour supply parameter (see Guerrón-Quintana and Nason, 2025).

Table 3. Prior and posterior estimates of the labour hoarding parameters

Parameter	Prior distribution	Prior mean (s.d.)	Posterior mode
φ_u	Gamma	0.05 (0.01)	0.06
φ_n	Gamma	25.0 (1.5)	13.9

[26] These parameters that are related to the foreign block and exogenous shock processes are not central to our paper.

[27] Capital share is set to 0.25, steady state price and wage markups are set to 1.2 as in the baseline model.

The posterior estimate of φ_u remains close to its prior mean, suggesting the data are consistent with the prior belief that labour utilisation is relatively flexible. The posterior estimate of φ_n shifts somewhat downward, suggesting that the data favour a more moderate degree of employment adjustment costs than implied by the prior.

Altogether, our estimation strategy is aimed at emphasising the role of labour hoarding. As noted earlier, the labour hoarding channel provides one possible explanation for the empirical regularities. In Section 6, we briefly discuss how to integrate different labour market channels to further improve the model's ability to match the empirical facts.

4.4 Impulse responses of the estimated labour hoarding model

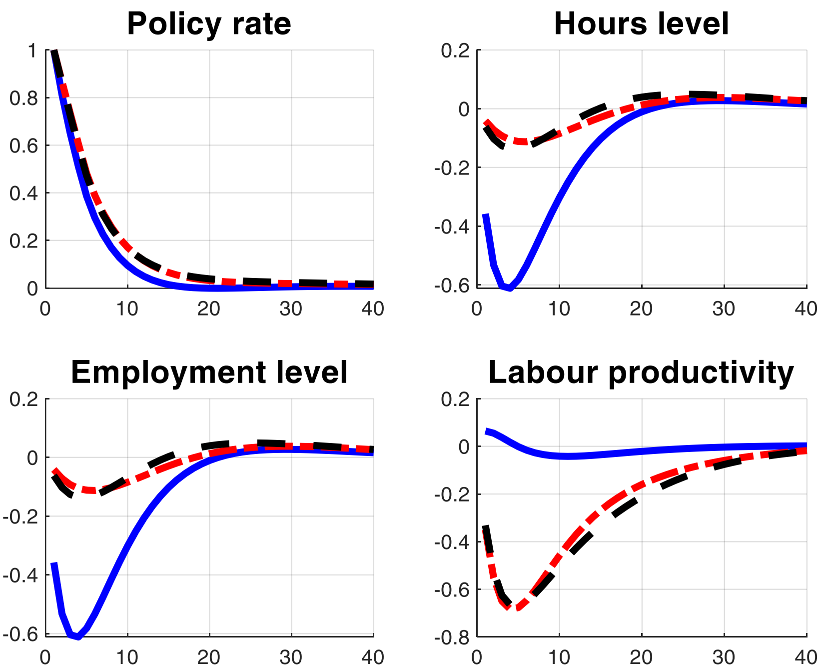
Having estimated the MAJA model with labour hoarding, we now examine the quantitative implications of the labour hoarding mechanism. Figure 4A-4C compare the impulse responses of labour productivity and other key macroeconomic variables to a contractionary monetary policy shock in the baseline MAJA model, the calibrated MAJA model with labour hoarding, and the estimated MAJA model with labour hoarding. The blue line represents the baseline model, the red line represents the calibrated labour hoarding model, and the black line represents the estimated labour hoarding model. To facilitate the comparisons, the impulse responses of the policy rate across three models are normalised to a one percentage point increase in the nominal policy rate.

The responses to the monetary policy shock from both calibrated and estimated labour hoarding models are similar. Relative to the baseline MAJA model, both calibrated and estimated labour hoarding models generate procyclical labour productivity, which is qualitatively consistent with Eichenbaum and Evans (2005), and Qiu and Ríos-Rull (2022). Moreover, the peak responses of labour productivity in both calibrated and estimated models are in line with our BVAR. Additionally, the calibrated and estimated models with labour hoarding produce a muted response of employment following the contractionary monetary policy shock. In both models, firms respond to weaker demand by reducing labour utilisation rather than adjusting employment, which is consistent with the labour hoarding mechanism. Therefore, the Okun coefficient implied by both calibrated and estimated labour hoarding models are below one. Lastly, both models generate a decline in the marginal product of labour and marginal cost.

The calibrated model demonstrates that the labour hoarding mechanism can account for the empirical labour productivity response identified by the BVAR model as well as to some extent, the second benchmark empirical Okun coefficient. The Bayesian estimation of the DSGE model provides additional support for the labour hoarding mechanism by combining prior information with the observed macroeconomic data to quantify the degree of labour utilisation flexibility and the cost of adjusting employment, rather than simply imposing them. The estimation indicates that labour utilisation is flexible, while adjusting employment is relatively costly.

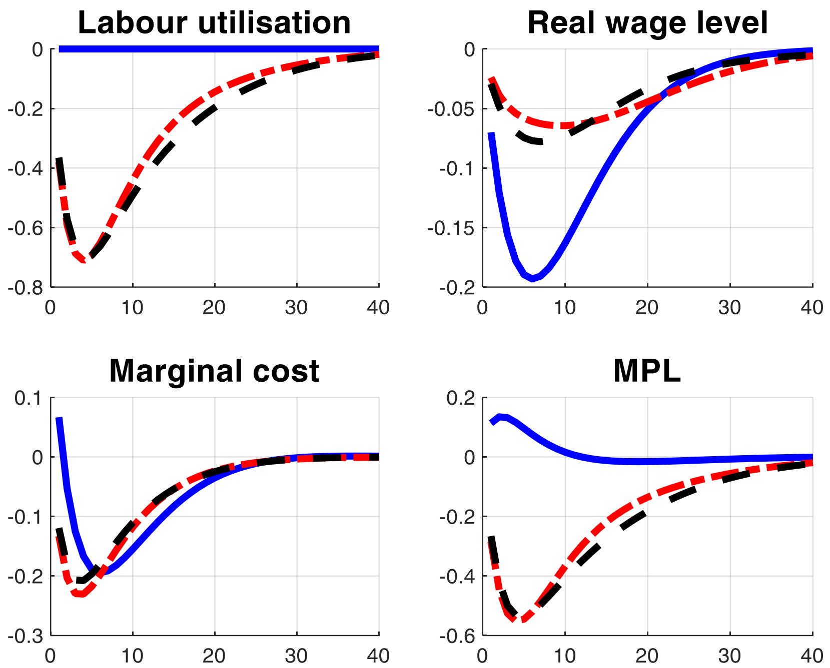
The two main takeaways from the calibration and estimation exercise are as follows. First, labour utilisation provides the relatively flexible intensive margin through which firms can vary the effective labour input after the monetary policy shock. The firms therefore rely less on the inflexible extensive margin of labour input, resulting in a substantially smaller employment and hours worked responses than in the baseline MAJA model. Thus, our labour hoarding mechanism allows the firms to absorb the gap between desired and actual employment through labour utilisation rather than employment. Second, both calibrated and estimated models with labour hoarding generate labour productivity and unemployment to output responses that are considerably closer to the empirical evidence than that of the baseline model without labour hoarding.

Figure 4A. Impulse responses to a contractionary monetary policy shock: baseline, calibrated and estimated labour hoarding models



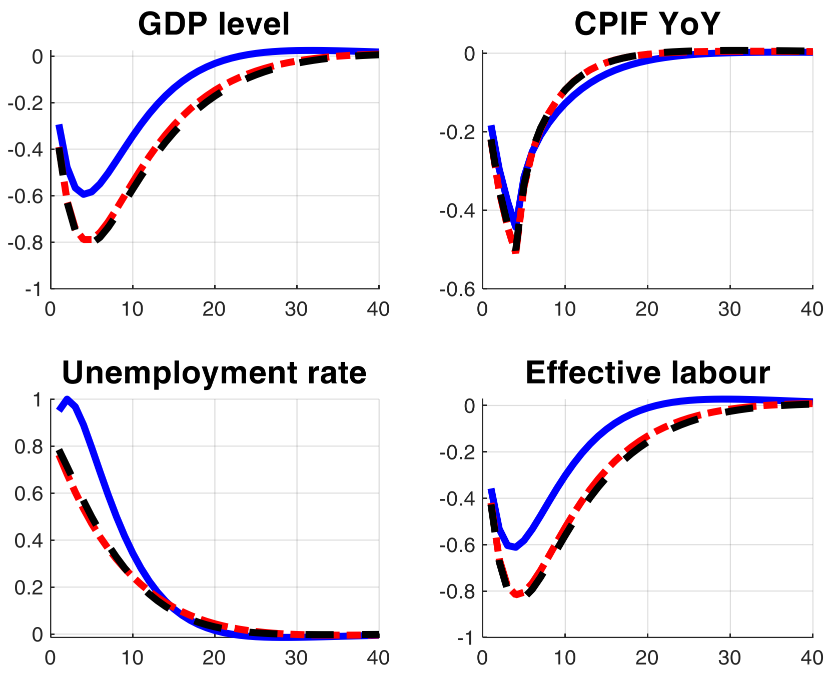
Note. The figure shows the effects of a contractionary monetary policy shock on key macroeconomic variables, and the responses of policy rate are normalised to one percentage point. The blue line represents the baseline MAJA, the red line represents the calibrated labour hoarding model, and the black line represents the estimated labour hoarding model. The CPIF is shown in annual percentage change and other variables in level.

Figure 4B. Impulse responses to a contractionary monetary policy shock: baseline, calibrated and estimated labour hoarding models



Note. The figure shows the effects of a contractionary monetary policy shock on key macroeconomic variables, and the responses of policy rate are normalised to one percentage point. The blue line represents the baseline MAJA, the red line represents the calibrated labour hoarding model, and the black line represents the estimated labour hoarding model. The CPIF is shown in annual percentage change and other variables in level.

Figure 4C. Impulse responses to a contractionary monetary policy shock: baseline, calibrated and estimated labour hoarding models



Note. The figure shows the effects of a contractionary monetary policy shock on key macroeconomic variables, and the responses of policy rate are normalised to one percentage point. The blue line represents the baseline MAJA, the red line represents the calibrated labour hoarding model, and the black line represents the estimated labour hoarding model. The CPIF is shown in annual percentage change and other variables in level.

5 Alternative specification of the labour utilisation cost function

In the benchmark specification as shown in Section 3, we specify the labour utilisation cost function as a quadratic function that is independent of wages. This section considers an alternative specification of the labour utilisation cost that varies proportionally with wages. Intuitively, higher labour effort requires additional compensation to workers, and in this case the labour utilisation cost is proportional to the firm's wage bill. The following alternative specification is given by:

$$W_t \phi(ef_t) = W_t \left[\frac{\gamma_u \varphi_u}{2} {ef_t}^2 + \gamma_u (1 - \varphi_u) ef_t + \gamma_u \left(\frac{\varphi_u}{2} - 1 \right) \right].$$

Given this alternative specification, we can derive the alternative labour hoarding condition. For expositional purposes, we show the associated log-linear equation:

$$\widehat{ef}_t = \frac{\varphi_n}{W \varphi_u} \left[\left(\hat{N}_t - \hat{N}_{t-1} \right) - \beta E_t \left(\hat{N}_{t+1} - \hat{N}_t \right) \right], \tag{10}$$

where φ_u is the labour utilisation cost parameter, and φ_n is the employment adjustment cost parameter. Eq. (10) is the labour hoarding condition under the alternative specification of labour utilisation cost. The main difference relative to the benchmark labour hoarding condition as shown in Eq. (9) is that labour utilisation is now only driven by employment adjustment costs. Specifically, higher adjustment costs of the extensive margin of labour input induce firms to rely more on the intensive margin of labour input through labour utilisation.

The intuition for why the real wage drops out of the labour hoarding condition under this alternative specification because changes in the real wage affects both the extensive margin and the intensive margin of labour input proportionally; therefore, the relative cost of the two labour input margins is unchanged. As a result, the employment adjustment costs are the only factor determining the labour hoarding condition, all else equal.

Similarly, we can think of an intermediate case in which wage movements partially affect labour hoarding dynamics. The resulting labour hording condition can be rewritten as:

$$\widehat{ef}_t = \frac{1}{\varphi_u}\left[\Omega_w \widehat{w}_t + \frac{\varphi_n}{W}\left[(\widehat{N}_t - \widehat{N}_{t-1}) \; - \; \beta E_t \left(\widehat{N}_{t+1} - \widehat{N}_t\right)\right]\right], \tag{11}$$

where Ω_w measures the degree to which wage movements influence labour utilisation. If $\Omega_w = 0$, labour utilisation is driven entirely by employment adjustment frictions which captured by Eq. (10). As Ω_w approaches 1, wage dynamics exert a stronger influence on labour utilisation. If $\Omega_w = 1$, we have the benchmark specification as in Eq. (9) where the labour utilisation is sensitive to changes in the real wage. This intermediate specification is a hybrid case between the wage sensitive labour hoarding case as Eq. (9) and the pure labour hoarding case as Eq. (10).

6 Discussion

Empirical evidence suggests labour productivity is procyclical to monetary policy shocks, whereas standard New Keynesian DSGE models struggle to produce procyclical labour productivity patterns. The main contribution of this paper is to introduce labour utilisation and employment adjustment costs into MAJA, a fully-fledged DSGE model to better account for procyclical labour productivity. There are several main lessons that we learn from this paper.

First, we derive a micro-founded labour hoarding condition in a dynamic general equilibrium framework. The key mechanism of labour hoarding is employment adjustment costs make firms more reluctant to adjust employment; thus, this creates the gap between desired and actual employment. The resulting gap is in turn absorbed by labour utilisation.

Second, the main reason to include both labour utilisation and employment adjustment costs is that having labour utilisation alone is insufficient to generate a meaningful procyclical labour productivity since the extensive margin of labour input would still be too flexible. Likewise, employment adjustment costs alone cannot generate procyclical labour productivity because without labour utilisation, there remains an almost one-to-one relationship between production and labour input. The key idea is to model the intensive margin to be relatively flexible to adjust, while the extensive margin of labour input is relatively costly to adjust.

Third, we calibrate and subsequently estimate the MAJA model with labour hoarding. Both the calibrated and estimated models with labour hoarding generate procyclical labour productivity in response to a monetary policy shock, in line with the evidence reported by Christiano, Eichenbaum and Evans (2005), and Qiu and Ríos-Rull (2022), whereas the baseline MAJA model—without this mechanism—produces acyclical productivity. Furthermore, the peak responses of labour productivity in both calibrated and estimated labour hoarding models are broadly in line with our BVAR estimate. Our calibrated and estimated labour hoarding model are also qualitatively consistent with the firm-level evidence reported by Gottfries, Mickelsson and Stadin (2026b) who find that production responds substantially more than employment in the short run following a demand shock.

Lastly, our models with labour hoarding mechanism also deliver an improvement in matching the empirical evidence of the Okun's law. Lindgren, Strid and Wang (2026) estimate the cross-country median Okun coefficient conditional on monetary policy shocks to be below one. In contrast to the model without labour hoarding, the Okun coefficients implied by our models with labour hoarding are below one.

There are some key differences between our paper and closely related studies. Burnside, Eichenbaum and Rebelo (1993) and Burnside and Eichenbaum (1996) incorporate labour effort into the Real business cycle (RBC) framework, and the households bear the cost of effort through the disutility of labour. Furthermore, Dossche, Gazzani and Lewis (2023) model labour effort as part of the household's labour supply decision in a general equilibrium framework. In our paper, firms determine labour utilisation and bear the cost of varying utilisation instead of household-side labour supply decision.

Our labour hoarding endogenously arises from the interaction between flexible labour utilisation and employment frictions. In a nutshell, our firm-side utilisation margin and labour hoarding mechanism inspired by Sbordone (1996) and Gottfries, Mickelsson and Stadin (2026a). In contrast to their work, we embed a labour hoarding mechanism into a fully-fledged DSGE model.

There are some directions for future empirical research. This paper focuses on labour utilisation as one of the factors that explain procyclicality of labour productivity. Drawing from Gottfries, Mickelsson and Stadin (2026a and 2026b), we can also explore the implication of increasing returns to scale for labour productivity. Since increasing returns to scale is already part of MAJA through the assumption of imperfect competition and fixed costs, the model can therefore be estimated jointly with labour utilisation and increasing returns. Furthermore, the labour market block in MAJA is based on the framework of Galí, Smets, and Wouters (2012) which has a wealth-induced labour supply channel and labour force participation constraint. By re-calibrating or estimating this wealth effect channel, this may improve the model's ability to match the empirical Okun relationship.

By combining our labour hoarding mechanism, the increasing returns to scale, and the labour supply wealth channel, this strategy may further enhance the model's ability to closely align with the empirical relationship between labour market variables, output and labour productivity. This avenue provides a more comprehensive framework for analysing the effects of monetary policy and other types of demand shocks on labour market and output.

Furthermore, we also find an interesting result concerning the role of technology shock. By embedding the labour hoarding mechanism, this considerably reduces the persistence of the temporary technology shock as shown in Table D2 in the Appendix. This finding is consistent with Gottfries, Mickelsson and Stadin (2026a and 2026b). The implication of labour hoarding for the role of technology shock is worthy of further study. In terms of future theoretical research, we can compare different specifications of the labour utilisation cost function more comprehensively. As demonstrated in this paper, the way a labour utilisation cost function is specified directly shapes the optimal labour hoarding condition.

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APPENDIX

Appendix A provides the derivations of firm's optimal decisions with labour utilisation and employment adjustment costs as well as the log-linear equations of the key conditions. Appendix B provides further details of BVAR specifications. Appendix C reports the parameter values used in the calibration of the labour hoarding model. Appendix D reports the parameter values used in the Bayesian estimation of the labour hoarding model.

Section A1: Firm's problem: first order conditions

The model extends the intermediate good producer's block of the MAJA DSGE model by allowing firms to vary not only the extensive margin of labour input, but also the intensity with which labour is used, denoted by labour utilisation or effort.

A representative intermediate firm employ workers (hours) N_t and capital services K_t to produce intermediate goods.[28] W_t is the nominal wage rate, and R_t^K is the rental rate. We introduce a new variable labour utilisation or effort ef_t.

When varying labour utilisation/effort, the firm faces the following labour cost function $\phi(ef_t)$ with the following properties: $\phi(1) = 0,\ \phi'(1) > 0\ and\ \phi''(1) > 0$, where $ef = 1$ denotes normal labour utilisation.

An example of the functional form can be specified as follows:

$$\phi(ef_t) = \frac{\gamma_u \varphi_u}{2} {ef_t}^2 + \gamma_u (1 - \varphi_u) ef_t + \gamma_u \left(\frac{\varphi_u}{2} - 1\right).$$

The first and second derivative are as follows:

$\phi'(ef_t) = \gamma_u \varphi_u ef_t + \gamma_u (1 - \varphi_u)$

$\phi''(ef_t) = \gamma_u \varphi_u.$

Evaluating these expressions at the steady state $ef = 1$ yields:

$\phi(1) = 0$

$\phi'(1) = \gamma_u$

$\phi''(1) = \gamma_u \varphi_u$

$\frac{\phi''(1)}{\phi'(1)} = \varphi_u\,.$

[28] In MAJA, labour is modelled as a single aggregate input, so there is no explicit distinction between hours worked and number of workers; both are captured by the same labour variable.

The function form of employment adjustment cost is given by:

$\Psi(N_t) = \frac{\varphi_n}{2}\left(\frac{N_t}{N_{t-1}} - 1\right)^2 N_{t-1}$, where N_{t-1} is a predetermined variable.

The derivative of $\Psi(N_t)$ with respect to N_t is as follows:

$$\frac{\partial\Psi(N_t)}{\partial N_t} = \varphi_n\left(\frac{N_t}{N_{t-1}} - 1\right).$$

The derivative of $\Psi(N_{t+1})$with respect to N_t is as follows:

$$\Psi(N_{t+1}) = \frac{\varphi_n}{2}\left(\frac{N_{t+1}}{N_t} - 1\right)^2 N_t$$

$$\frac{\partial\Psi(N_{t+1})}{\partial N_t} = \frac{\varphi_n}{2}\left(\frac{N_{t+1}}{N_t} - 1\right)^2 - \varphi_n \frac{N_{t+1}}{(N_t)^2} N_t \left(\frac{N_{t+1}}{N_t} - 1\right)$$

$$\frac{\partial\Psi(N_{t+1})}{\partial N_t} = \frac{\varphi_n}{2}\left(\frac{N_{t+1}}{N_t} - 1\right)^2 - \varphi_n\left(\frac{N_{t+1}}{N_t} - 1\right)\frac{N_{t+1}}{N_t}.$$

The cost minimization problem of the intermediate firm is can be defined as follows:

Min

$$N_t W_t + K_t R_t^K + N_t \phi(ef_t) + \Psi(N_t)$$

$$(ef_t N_t)^{1-\alpha} K_t^\alpha \geq \left(\frac{P_{it}}{P_t}\right)^{-\frac{\lambda_t^d}{\lambda_t^d - 1}} Y_t .$$

$$\mathcal{L} = E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \begin{array}{c} N_t W_t + K_t R_t^K + N_t \phi(ef_t) + \Psi(N_t) \\ -\mu_t\left((ef_t N_t)^{1-\alpha} K_t^\alpha - \left(\frac{P_{it}}{P_t}\right)^{-\frac{\lambda_t^d}{\lambda_t^d - 1}} Y_t \right) \end{array} \right\}.$$

$$\frac{\partial\mathcal{L}}{\partial N_t} = W_t + \phi(ef_t) + \varphi_n\left(\frac{N_t}{N_{t-1}} - 1\right) + \beta E_t\left[\frac{\varphi_n}{2}\left(\frac{N_{t+1}}{N_t} - 1\right)^2 - \varphi_n\left(\frac{N_{t+1}}{N_t} - 1\right)\frac{N_{t+1}}{N_t}\right]$$

$$-\mu_t[(1-\alpha)(ef_t)^{1-\alpha} N_t^{-\alpha} \epsilon_t K_t^\alpha] = 0 \tag{A.1}$$

$$\frac{\partial\mathcal{L}}{\partial K_t} = R_t^K - \mu_t[\alpha(ef_t N_t)^{1-\alpha} \epsilon_t K_t^{\alpha-1}] = 0 \tag{A.2}$$

$$\frac{\partial\mathcal{L}}{\partial ef_t} = N_t \phi'(ef_t) - \mu_t[(1-\alpha) ef_t^{-\alpha} (N_t)^{1-\alpha} \epsilon_t K_t^\alpha] = 0 \tag{A.3}$$

Derivation of marginal product of labour:

$$MPL_t = (1-\alpha)(ef_t)^{1-\alpha} \epsilon_t \left(\frac{K_t}{N_t}\right)^\alpha \tag{A.4}$$

Derivation of marginal product of capital:

$$MPK_t = \alpha(ef_t)^{1-\alpha} \epsilon_t \left(\frac{K_t}{N_t}\right)^{-(1-\alpha)} \tag{A.5}$$

F.O.C wrt N_t:

$$W_t + \phi(ef_t) + \varphi_n\left(\frac{N_t}{N_{t-1}} - 1\right) + \beta E_t\left[\frac{\varphi_n}{2}\left(\frac{N_{t+1}}{N_t} - 1\right)^2 - \varphi_n\left(\frac{N_{t+1}}{N_t} - 1\right)\frac{N_{t+1}}{N_t}\right]$$

$$-\mu_t[(1-\alpha)(ef_t)^{1-\alpha}N_t^{-\alpha}\epsilon_t K_t^{\alpha}] = 0$$

$$MC_t[(1-\alpha)(ef_t)^{1-\alpha}N_t^{-\alpha}\epsilon_t K_t^{\alpha}] =$$

$$W_t + \phi(ef_t) + \varphi_n\left(\frac{N_t}{N_{t-1}} - 1\right) + \beta E_t\left[\frac{\varphi_n}{2}\left(\frac{N_{t+1}}{N_t} - 1\right)^2 - \varphi_n\left(\frac{N_{t+1}}{N_t} - 1\right)\frac{N_{t+1}}{N_t}\right] \quad \text{(A.6)}$$

Using a first-order approximation, the expression inside the square brackets simplifies to:

$$\frac{\varphi_n}{2}\left(\frac{N_{t+1}}{N_t} - 1\right)^2 - \varphi_n\left(\frac{N_{t+1}}{N_t} - 1\right)\frac{N_{t+1}}{N_t} \approx -\varphi_n\left(\frac{N_{t+1}}{N_t} - 1\right).$$

This approximation yields a tractable linear representation of the employment adjustment costs. We can rewrite the FOC for employment expression as:

$$MC_t[(1-\alpha)(ef_t)^{1-\alpha}N_t^{-\alpha}\epsilon_t K_t^{\alpha}] =$$

$$W_t + \phi(ef_t) + \varphi_n\left(\frac{N_t}{N_{t-1}} - 1\right) - \beta E_t\left[\varphi_n\left(\frac{N_{t+1}}{N_t} - 1\right)\right] \quad \text{(A.7)}$$

Given $MPL_t = (1-\alpha)(ef_t)^{1-\alpha}\epsilon_t\left(\frac{K_t}{N_t}\right)^{\alpha}$, we can rewrite the expression as:

$$MC_t MPL_t = W_t + \phi(ef_t) + \varphi_n\left(\frac{N_t}{N_{t-1}} - 1\right) - \beta E_t\left[\varphi_n\left(\frac{N_{t+1}}{N_t} - 1\right)\right]$$

$$MC_t = \frac{W_t + \phi(ef_t) + \varphi_n\left(\frac{N_t}{N_{t-1}} - 1\right) - \beta E_t\left[\varphi_n\left(\frac{N_{t+1}}{N_t} - 1\right)\right]}{MPL_t} \quad \text{(A.8)}$$

F.O.C wrt K_t:

$$R_t^K = MC_t[\alpha(ef_t N_t)^{1-\alpha}\epsilon_t K_t^{\alpha-1}]$$

$$R_t^K = MC_t\left[\alpha(ef_t)^{1-\alpha}\epsilon_t\left(\frac{K_t}{N_t}\right)^{-(1-\alpha)}\right]$$

Given $MPK_t = \alpha(ef_t)^{1-\alpha}\epsilon_t\left(\frac{K_t}{N_t}\right)^{-(1-\alpha)}$, we have the FOC for capital services:

$$R_t^K = MC_t MPK_t \quad \text{(A.10)}$$

F.O.C wrt ef_t:

$$N_t\phi'(ef_t) - \mu_t[(1-\alpha)ef_t^{-\alpha}(N_t)^{1-\alpha}\epsilon_t K_t^{\alpha}] = 0$$

$$MC_t[(1-\alpha)ef_t^{-\alpha}(N_t)^{1-\alpha}\epsilon_t K_t^{\alpha}] = N_t\phi'(ef_t)$$

$$MC_t[(1-\alpha)ef_t^{-\alpha}(N_t)^{-\alpha}\epsilon_t K_t^{\alpha}] = \phi'(ef_t)$$

$$MC_t\left[(1-\alpha)ef_t^{-\alpha}\epsilon_t\left(\frac{K_t}{N_t}\right)^{\alpha}\right] = \phi'(ef_t)$$

Given $MPL_t = (1-\alpha)(ef_t)^{1-\alpha}\epsilon_t\left(\frac{K_t}{N_t}\right)^{\alpha}$, we can rewrite the above equation as:

$$MC_t \left[(1-\alpha) ef_t^{1-\alpha} \epsilon_t \left(\frac{K_t}{N_t}\right)^{\alpha} \right] = \phi'(ef_t) ef_t$$

$$MC_t MPL_t = \phi'(ef_t) ef_t \tag{A.11}$$

or

$$MC_t MPL_t = [\gamma_u \varphi_u ef_t + \gamma_u (1-\varphi_u)] ef_t \tag{A.12}$$

Section A2: List of key non-linear equations and stationary equations

Marginal cost of production

$$MC_t = \frac{W_t + \phi(ef_t) + \varphi_n\left(\frac{N_t}{N_{t-1}} - 1\right) - \beta E_t\left[\varphi_n\left(\frac{N_{t+1}}{N_t} - 1\right)\right]}{MPL_t}$$

$$W = MC * MPL$$

Marginal product of labour

$$MPL_t = (1-\alpha)(ef_t)^{1-\alpha} \epsilon_t \left(\frac{K_t}{N_t}\right)^{\alpha}$$

$$MPL = (1-\alpha)(ef)^{1-\alpha} \epsilon \left(\frac{K}{N}\right)^{\alpha}$$

Marginal product of capital services

$$MPK_t = \alpha(ef_t)^{1-\alpha} \epsilon_t \left(\frac{K_t}{N_t}\right)^{-(1-\alpha)}$$

$$MPK = \alpha(ef)^{1-\alpha} \epsilon \left(\frac{K}{N}\right)^{-(1-\alpha)}$$

Rental capital service

$$R_t^K = MC_t MPK_t$$

$$R^K = MCMPK$$

Optimal Labour effort condition

$$MC_t MPL_t = \phi'(ef_t) ef_t$$

$$W = \phi'(1) = \gamma_u$$

Given the properties of this labour utilisation cost function, the first order conditions for labour demand and labour utilisation are jointly satisfied in the deterministic steady state.

Production function

$$Y_t = (ef_t N_t)^{1-\alpha} \epsilon_t K_t^{\alpha}$$

$$Y = (efN)^{1-\alpha} \epsilon K^{\alpha}$$

Section A3: Derivations of log-linear equations

Log-linear of MPN_t

$$MPL_t = (1-\alpha)(ef_t)^{1-\alpha}\epsilon_t\left(\frac{K_t}{N_t}\right)^{\alpha}$$

$$\widehat{MPL}_t = (1-\alpha)\widehat{ef}_t + \hat{\epsilon}_t + \alpha(\hat{K}_t - \hat{N}_t) \quad \text{(B.1)}$$

Log-linear of MPK_t

$$MPK_t = \alpha(ef_t)^{1-\alpha}\epsilon_t\left(\frac{K_t}{N_t}\right)^{-(1-\alpha)}$$

$$\widehat{MPK}_t = (1-\alpha)\widehat{ef}_t + \hat{\epsilon}_t - (1-\alpha)(\hat{K}_t - \hat{N}_t) \quad \text{(B.2)}$$

Log-linear of MC_t

$$MC_t = \frac{W_t + \phi(ef_t) + \varphi_n\left(\frac{N_t}{N_{t-1}} - 1\right) - \beta E_t\left[\varphi_n\left(\frac{N_{t+1}}{N_t} - 1\right)\right]}{MPL_t}$$

$$MC_t MPL_t = W_t + \phi(ef_t) + \varphi_n\left(\frac{N_t}{N_{t-1}} - 1\right) - \beta E_t\left[\varphi_n\left(\frac{N_{t+1}}{N_t} - 1\right)\right]$$

$$MCMPL\left[\widehat{MC}_t + \widehat{MPL}_t\right] = W\hat{W}_t + \phi'(ef)ef\widehat{ef}_t + \varphi_n\left(\hat{N}_t - \hat{N}_{t-1}\right)\frac{N}{N} - \beta\varphi_n\left(\hat{N}_{t+1} - \hat{N}_t\right)\frac{N}{N}$$

$$MCMPL\left[\widehat{MC}_t + \widehat{MPL}_t\right] = W\hat{W}_t + \phi'(ef)ef\widehat{ef}_t + \varphi_n\left(\hat{N}_t - \hat{N}_{t-1}\right) - \varphi_n\beta E_t\left(\hat{N}_{t+1} - \hat{N}_t\right)$$

Given $\phi'(1) = W = \gamma_u$, we have:

$$MCMPL\left[\widehat{MC}_t + \widehat{MPL}_t\right] = W\hat{W}_t + W\widehat{ef}_t + \varphi_n\left(\hat{N}_t - \hat{N}_{t-1}\right) - \varphi_n\beta E_t\left(\hat{N}_{t+1} - \hat{N}_t\right)$$

Given $MCMPL = W$, we have:

$$\left[\widehat{MC}_t + \widehat{MPL}_t\right] = \hat{W}_t + \widehat{ef}_t + \frac{1}{W}\left[\varphi_n\left(\hat{N}_t - \hat{N}_{t-1}\right) - \varphi_n\beta E_t\left(\hat{N}_{t+1} - \hat{N}_t\right)\right] \quad \text{(B.3)}$$

Log-linear of R_t^K

$$\hat{R}_t^K = \widehat{MC}_t + \widehat{MPK}_t \quad \text{(B.4)}$$

Log-linear of labour utilisation condition

$$MC_t MPL_t = \phi'(ef_t)ef_t$$

$$MC_t MPL_t / ef_t = \phi'(ef_t)$$

$$MCMPL\left[\widehat{MC}_t + \widehat{MPL}_t - \widehat{ef}_t\right] + MCMPL = \phi'(1) + \phi''(1)\widehat{ef}_t$$

Where $MCMPL = W = \phi'(1)$, we have:

$W\left[\widehat{MC}_t + \widehat{MPL}_t - \widehat{ef}_t\right] + W = W + \phi''(1)\widehat{ef}_t$

$W\left[\widehat{MC}_t + \widehat{MPL}_t\right] = W\widehat{ef}_t + \phi''(1)\widehat{ef}_t$

$W\left[\widehat{MC}_t + \widehat{MPL}_t\right] = [W + \phi''(1)]\widehat{ef}_t$

$\widehat{ef}_t = \frac{W}{[W+\phi''(1)]}\left[\widehat{MC}_t + \widehat{MPL}_t\right]$

Given $W = \phi'(1)$ and $\frac{\phi''(1)}{\phi'(1)} = \varphi_u$, we have:

$\widehat{ef}_t = \frac{1}{[1+\varphi_u]}\left[\widehat{MC}_t + \widehat{MPL}_t\right]$

Log-linear of production function

$Y_t = (ef_t N_t)^{1-\alpha}\epsilon_t K_t^{\alpha}$

$\widehat{Y}_t = (1-\alpha)\widehat{N}_t + (1-\alpha)\widehat{ef}_t + \alpha\widehat{K}_t + \hat{\epsilon}_t$ or $\widehat{Y}_t = \widehat{MPL}_t + \widehat{N}_t$

Summary of log-linearised equations

1. $\widehat{MPL}_t = (1-\alpha)\widehat{ef}_t + \hat{\epsilon}_t + \alpha(\widehat{K}_t - \widehat{N}_t)$
2. $\widehat{MPK}_t = (1-\alpha)\widehat{ef}_t + \hat{\epsilon}_t - (1-\alpha)(\widehat{K}_t - \widehat{N}_t)$
3. $\left[\widehat{MC}_t + \widehat{MPL}_t\right] = \widehat{W}_t + \widehat{ef}_t + \frac{1}{W}\left[\varphi_n\left(\widehat{N}_t - \widehat{N}_{t-1}\right) - \varphi_n \beta E_t\left(\widehat{N}_{t+1} - \widehat{N}_t\right)\right]$
4. $\widehat{R}_t^K = \widehat{MC}_t + \widehat{MPK}_t$
5. $\widehat{ef}_t = \frac{1}{[1+\varphi_u]}\left[\widehat{MC}_t + \widehat{MPL}_t\right]$
6. $\widehat{Y}_t = (1-\alpha)\widehat{N}_t + (1-\alpha)\widehat{ef}_t + \alpha\widehat{K}_t + \hat{\epsilon}_t$

Section B: BVAR specification

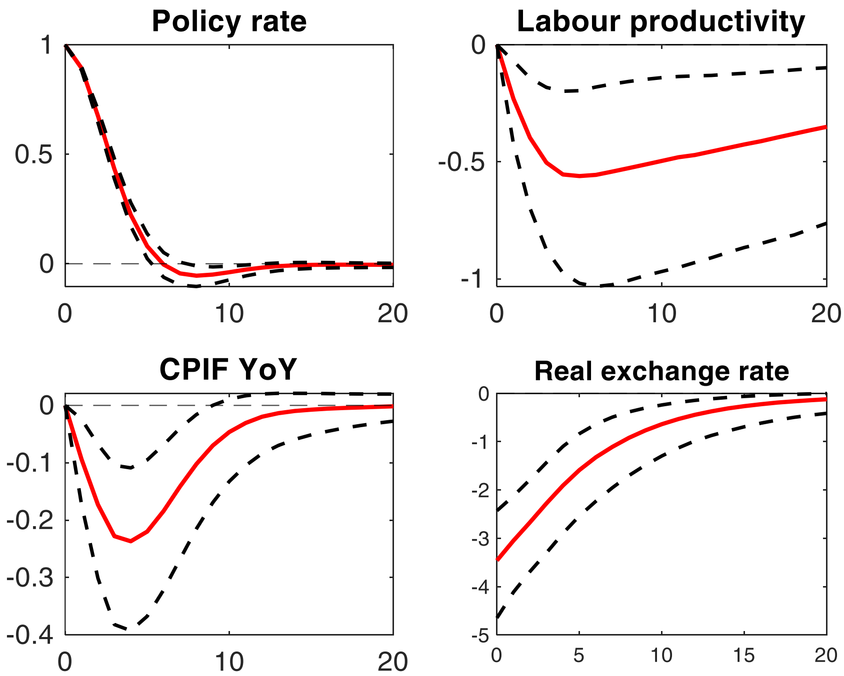
Baseline BVAR specification: the Bayesian VAR is estimated using quarterly data from 1995Q2 to 2024Q4 with 4 lags. The endogenous variables are labour productivity ($\ln$ productivity), CPIF inflation (year-on-year), the policy rate, and the real exchange rate ($\ln$ RER).

Exogenous variables include a constant, foreign GDP ($\ln$ KIX GDP), foreign inflation (KIX CPI inflation), and the foreign policy rate (KIX policy rate) are included as strictly exogenous regressors to account for external economic conditions. A normal-diffuse prior is employed with hyperparameters: $\lambda_1 = 0.1$, $\lambda_2 = 0.5$, $\lambda_3 = 1$, $\lambda_4 = 100$, $\lambda_6 = 0.1$, and $\lambda_7 = 0.001$.

Posterior inference is based on 7,000 MCMC draws with 2,000 burn-in iterations. Monetary policy shocks are identified using a recursive (Cholesky) decomposition with the ordering [Labour productivity, Inflation, Policy rate, Real exchange rate]. Impulse responses are reported with 68% Bayesian credible intervals.

Robust check: To account for the COVID-19 pandemic, the BVAR includes an exogenous dummy variable equal to one from 2020Q1 to 2021Q4 and zero otherwise. The impulse responses are qualitatively unchanged compared with the baseline specification.

Figure B1. BVAR: Impulse responses to a monetary policy shock



Section C: DSGE calibration

This appendix reports the parameter values used in the calibration of the labour-hoarding model. The calibration builds on the posterior estimates of the baseline MAJA model, estimated using Bayesian methods on Swedish, euro-area and U.S. data over the period 1995Q2–2024Q4. Except for the labour hoarding parameters, all parameter values are set equal to the posterior estimates of the baseline MAJA model.

Table C1. Core structural parameters inherited from the baseline MAJA model

Parameter	Description	Calibrated value
b	Habit persistence	0.738
xid	Calvo for domestic goods	0.836
$ximc$	Calvo for import consumption goods	0.837
$ximi$	Calvo for import investment goods	0.558
$ximx$	Calvo for import export goods	0.727
xiw	Calvo for wages	0.741
xix	Calvo for export goods	0.756
$etac$	Elasticity of substitution between domestic and imported consumption goods	0.585
$etai$	Elasticity of substitution between domestic and imported investment goods	0.372
$etaf$	Elasticity of substitution between domestic and imported goods	0.423
$etax$	Elasticity of substitution between domestic and imported export goods	1.696
$phitildes$	UIP risk premium parameter	0.168
$siga$	Labour disutility parameter	0.436
$sigL$	Labour disutility parameter	3.010
$rhoR$	Interest-rate smoothing parameter	0.922
rpi	Monetary policy response to inflation	1.465
ry	Monetary policy response to unemployment rate	0.245
$rdeltay$	Monetary policy response to the change in the unemployment rate	0.086

Table C2. Additional domestic structural and persistence parameters inherited from the baseline MAJA model

Parameter	Description	Calibrated value
$alpha$	Capital share	0.25
$Stilde2prime\string^ss$	Investment adjustment cost parameter	7.344
$Lambdad\_ss$	Steady state price markup	1.2
$Lambdaw\_ss$	Steady state wage markup	1.2
$rkhi$	Effect of the domestic SW risk premium shock on the domestic neutral interest rate	0.561
rho_pce	Persistence of the energy (relative price) shock	0.933
$rho\_epsilon$	Persistence of the temporary technology shock	0.810
rho_g	Persistence of the government spending shock	0.175
rho_khi	Persistence of the SW risk premium shock	0.764
rho_zetah	Persistence of the labour supply shock	0.738
$rho\_phitilde$	Persistence of the UIP risk premium shock	0.850
rho_lambda_w	Persistence of the wage markup shock	0.492
rho_lambda_d	Persistence of the domestic price markup shock	0.930
rho_lambda_mc	Persistence of the import consumption price markup shock	0.714

Section D: DSGE Bayesian estimation

This appendix reports the parameterisation underlying the Bayesian estimation of the labour hoarding model. To isolate the contribution of the labour hoarding mechanism, the structural parameters that are related to monetary transmissions are fixed at their posterior modes from the baseline MAJA model. The remaining parameters, including the labour hoarding parameters, are estimated using Bayesian methods.

Table D1. Structural parameters fixed in the Bayesian estimation of the labour hoarding model

The structural parameters reported in Table D1 are fixed at the posterior modes of the baseline MAJA model throughout the Bayesian estimation of the labour hoarding model. These parameters are therefore not re-estimated.

Parameter	Description	Baseline
b	Habit persistence	0.738
xid	Calvo for domestic goods	0.836
$ximc$	Calvo for import consumption goods	0.837
$ximi$	Calvo for import investment goods	0.558
$ximx$	Calvo for import export goods	0.727
xiw	Calvo for wages	0.741
xix	Calvo for export goods	0.756
$etac$	Elasticity of substitution between domestic and imported consumption goods	0.585
$etai$	Elasticity of substitution between domestic and imported investment goods	0.372
$etaf$	Elasticity of substitution between domestic and imported goods	0.423
$etax$	Elasticity of substitution between domestic and imported export goods	1.696
$phitildes$	UIP risk premium parameter	0.168
$siga$	Labour disutility parameter	0.436
$sigL$	Labour disutility parameter	3.010
$rhoR$	Interest-rate smoothing parameter	0.922
rpi	Monetary policy response to inflation	1.465
ry	Monetary policy response to unemployment rate	0.245
$rdeltay$	Monetary policy response to the change in the unemployment rate	0.086

Table D2. Prior and posterior parameter estimates: baseline MAJA and the labour hoarding model

The table reports the prior means together with the posterior modes for the estimated parameters. A dash indicates that the corresponding parameter is not included in the baseline MAJA model.

Parameter	Description	Prior mean	Baseline posterior mode	Labour-hoarding posterior mode
Labour hoarding parameters				
$phiu$	Labour utilisation adjustment parameter	0.05	–	0.056
$phin$	Employment adjustment cost parameter	25	–	13.903
Domestic structural parameters				
$Stilde2prime\_ss$	Investment adjustment cost parameter	6	7.344	7.300
$rkhi$	SW risk premium coefficient in the neutral interest rate equation	0	0.561	0.558
Domestic shock persistence parameters				
rho_pce	Persistence of the energy (relative price) shock	0.75	0.933	0.857
$rho\_epsilon$	Persistence of the temporary technology shock	0.75	0.809	0.137
rho_g	Persistence of the government spending shock	0.75	0.175	0.326
rho_khi	Persistence of the SW risk premium shock	0.75	0.764	0.767
rho_zetah	Persistence of the labour disutility shock	0.75	0.738	0.696
$rho\_phitilde$	Persistence of the UIP risk premium shock	0.75	0.850	0.802
$rho\_lambdaw$	Persistence of the wage markup shock	0.75	0.492	0.499
$rho\_lambdad$	Persistence of the domestic price markup shock	0.75	0.930	0.521

$rho\_lambdamc$	Persistence of the import consumption price markup shock	0.75	0.7139	0.736
Domestic shock standard deviations				
sig_pce	Std. dev. energy (relative price) shock	0.5	0.555	0.539
$sig\_epsilon$	Std. dev. temporary technology shock	0.5	0.737	1.623
sig_epsR	Std. dev. monetary policy shock	0.25	0.441	0.442
sig_g	Std. dev. government spending shock	0.25	0.173	0.230
sig_khi	Std. dev. SW risk premium shock	0.25	0.353	0.351
$sig\_lambdad$	Std. dev. domestic price markup shock	0.2	0.222	0.421
$sig\_lambdamc$	Std. dev. import consumption price markup shock	0.5	0.863	0.845
$sig\_lambdami$	Std. dev. import investment price markup shock	0.2	0.236	0.402
$sig\_lambdamx$	Std. dev. export price markup shock	0.5	0.400	0.496
$sig\_lambdax$	Std. dev. import intermediate price markup shock	0.5	0.677	0.676
$sig\_phitilde$	Std. dev. UIP risk premium shock	0.25	0.294	0.440
$sig\_upsilon$	Std. dev. temporary investment shock	0.25	0.267	0.264
sig_zetac	Std. dev. consumption preference shock	0.25	0.274	0.306
sig_zetah	Std. dev. labour disutility shock	0.25	0.510	0.957
$sig\_lambdaw$	Std. dev. wage markup shock	2	2.039	2.475
sig_pibarc	Std. dev. inflation trend shock	0.1	0.093	1.387
sig_mupsi	Std. dev. permanent investment-specific technology shock	0.25	0.258	0.277
Foreign structural parameters				
b_f	Habit persistence	0.75	0.664	0.665
xi_f	Price stickiness	0.6	0.753	0.649
xiw_f	Wage stickiness	0.6	0.420	0.345

$sigL\_f$	Inverse Frisch elasticity	4	2.323	2.862
$Stilde2prime\_f\_ss$	Investment adjustment cost	3	3.343	3.871
$rhoR\_f$	Interest rate smoothing	0.75	0.932	0.930
rpi_f	Response to inflation	1.75	1.498	1.690
ry_f	Response to output growth	0.1	0.168	0.184
$rdeltay\_f$	Response to output growth change	0.05	0.088	0.055

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