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# UK monetary policy in an estimated DSGE model with state-dependent price and wage contracts

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ABSTRACT

This study incorporates state-dependent price/wage setting into a small open economy DSGE model to investigate whether, with this feature, the model can better explain the UK business cycle dynamics. The model is estimated and tested using the Indirect Inference method and is found to fit the dynamic behaviour of key variables very well over a long sample period 1955–2021 which includes episodes with the Zero lower Bound, ZLB. The model implications for policy improvement are that in the presence of state-dependence and the ZLB, monetary-fiscal coordination is needed to stabilise the economy, as monetary policy alone cannot achieve economic stability during ZLB scenarios, where it must use bond purchases (Quantitative Easing, QE). Our findings suggest that a coordinated monetary-fiscal policy framework, i.e., an interest rate policy that targets nominal GDP complemented by a ZLB-suppressing fiscal policy, decreases the frequency of economic crises and enhances price/output stability and household welfare compared to the baseline Taylor Rule and QE framework.

## 1. Introduction

DSGE models with price/wage-setting behaviour are widely used for understanding the dynamics of macroeconomic variables and for policy analysis. There is ongoing debate about whether prices and wages should be time-dependent or state-dependent. The prevailing paradigm of monetary economics, the New Keynesian (NK) model, uses the Calvo (1983) model of time-dependent price and wage stickiness, where firms/labour unions have a fixed probability of changing their own prices/wages in each period, equivalent to a fixed duration contract. On the other hand, the classical theory emphasises that prices/wages are fully flexible and that its contract equivalents are fully state-contingent contracts; thus, agents could achieve optimal outcomes. However, given the existence of menu costs, it may be optimal for agents to ignore small shocks and maintain prices unchanged for some duration, as the cost of changing prices may exceed the cost of the shocks in this case. The cost of shocks they would ignore in such a way and the duration they would be willing to keep prices constant would be state-dependent. In contrast, when the cost of not responding to the shocks is higher than the cost of these shocks, it would be optimal for the agents to adjust their prices. In other words, the price contract durations are state-dependent, but not fully flexible in the presence of the menu costs. Similarly, state-dependent wage contracts are based on the idea that the fixed costs of renegotiating employment contracts prevent frequent wage adjustments; and these fixed costs mean that the

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probability and the magnitude of wage changes vary with the state of the economy.

The nature of price/wage setting has a crucial implication for the effectiveness of monetary policy in stabilising the business cycle. Flexible price/wage adjustments absorb shocks and largely dampen the impact of monetary shocks. Conversely, when prices/wages show a high level of stickiness, monetary shocks can have a pronounced effect on output, thus facilitating the stabilisation of the business cycle.

A substantial amount of evidence from micro-level studies across various countries (e.g., Nakamura et al., 2018; Alvarez et al., 2019; Grajales et al., 2019; Rudolf and Seiler, 2022) suggests that the durations of price/wage contracts are state-dependent, particularly influenced by inflation. However, the macroeconomic literature incorporating this state-dependence into DSGE models remains limited (Takahashi, 2018; Costain et al., 2019, 2022; Le et al., 2021), and these models feature closed-economy setups and are applied to US data. In this paper, we extend the framework to a small open economy DSGE model, which is more suitable for describing open economies such as the UK and Japan. We incorporate state-dependence into this model and use the Indirect Inference estimation and testing procedure to investigate whether there is macro-level evidence supporting this incorporation of micro-level evidence of state dependence into a UK DSGE model. That is, whether this additional feature helps the model improve its ability to explain the business cycle dynamics of the UK.

This small open economy DSGE model extends the Smets and Wouters (2007) (SW07) model by combining the NK and New Classical (NC) models into a hybrid model (Le et al., 2011), adding the financial frictions of Bernanke et al. (1999) (BGG) and incorporating the new monetary developments following the recent Great Financial Crisis (GFC), i.e., the Zero Lower Bound (ZLB) and Quantitative Easing (QE) (Le et al., 2016b). Regarding the extension of the model to an open economy, our foreign block builds on the spirit of Gali and Monacelli (2005) and Lyu et al. (2023), introducing exchange rates, foreign bonds, exports, and imports, and distinguishing between the CPI and the price index of goods produced domestically. To incorporate state-dependence, we assume that a fraction of goods/labour markets have flexible prices/wages while the rest have sticky prices/wages, and the fraction of firms/labour unions with nominal rigidity is state-dependent and varies with past inflation.

This paper estimates and tests a state-dependent DSGE model on unfiltered UK macroeconomic data over the period 1955Q1-2021Q1 using the simulation-based Indirect Inference method. The main findings and contributions of this study are that the state-dependent model fits the dynamic behaviour of the key variables over the sample period, with the price/wage contract durations fluctuating with the state of the economy (inflation) throughout the whole sample period. However, the incorporation of state-dependence in DSGE models challenges previous findings by Falagiarda (2014) and Lyu et al. (2023) on QE's effectiveness in stabilising the UK economy, as conventional monetary policy struggles to stabilise inflation during ZLB periods, leading to increased price duration volatility, which in turn exacerbates inflation volatility. Therefore, this study explores a ZLB-suppressing fiscal rule. Meanwhile, Nominal GDP targeting is gaining interest as a potentially more effective alternative to inflation targeting (Beckworth and Hendrickson, 2020; Billi, 2020; Le et al., 2021, 2023), while research on its application within state-dependent DSGE models remains scarce. Thus, this study assesses the effectiveness of combining a Nominal GDP targeting rule with a fiscal ZLB-suppression policy as an alternative policy regime. In the presence of state-dependence, we find that this coordinated monetary-fiscal policy framework implies a modest rise in interest rate variability and outperforms the baseline Taylor Rule with QE in avoiding crises and reducing welfare costs, and it stabilises both inflation and output more strongly under demand shocks than the baseline framework. To the best of our knowledge, this paper is the first macro-level empirical study of state-dependent price/wage contracts in an open economy context.

The rest of this paper is organised as follows. Section 2 provides a literature review. Section 3 sets up a state-dependent DSGE model in which both price and wage contracts change endogenously with the state of the economy rather than merely being time-dependent. Specifically, price/wage durations depend on the variance of lagged inflation, which in turn depends on durations. Section 4 briefly discusses the Indirect Inference method and the data used. Section 5 presents the empirical results. Section 6 analyses policy implications. Section 7 concludes the paper.

## 2. Literature review

A growing body of literature at the micro-level has shown state-dependent pricing, see Bhattarai and Schoenle (2014) and Nakamura et al. (2018) for the US, Nilsen et al. (2018) and Wulfsberg (2016) for Norway, Dedola et al. (2021) for Denmark, Rudolf and Seiler (2022) for Switzerland, Alvarez et al. (2019) for Argentina, Konieczny and Skrzypacz (2005) for Poland, and Gagnon (2009) for Mexico.

Micro-level evidence of state-dependent pricing has also been found in the UK. Bunn and Ellis (2012a) investigated UK consumer price behaviour and found that the probability of a price change did not remain fixed over time but varied between years and months. Furthermore, there was evidence of a correlation between the probability of monthly price increase and headline inflation over the period 1996–2006, but less evidence of a link between the probability of price decrease and inflation. Bunn and Ellis (2012b) examined monthly UK producer price behaviour over the period 2003–2007 and showed that the probability of price changes was not fixed. Zhou and Dixon (2019) explored price-setting behaviour in the UK using Consumer Price Index (CPI) and Producer Price Index microdata during the Great Moderation period 1996–2007, revealing that prices were indeed fixed for average durations, but they were state-dependent. Dixon et al. (2020) examined the impact of the GFC on firm's pricing behaviour using UK CPI microdata for the period 1996–2013 and found strong evidence of a relationship between the frequency of price change and inflation, with inflation tending to increase the frequency of price changes, primarily by increasing the frequency of price increases. Petrella et al. (2018) used monthly micro price data underlying the UK CPI from 1996 to 2017 and showed a considerable degree of positive co-movement between price changes and inflation. Moreover, they illustrated that state-dependence plays a crucial role in price setting; when inflation is high and volatile, the extensive margin of price adjustment (adjustments driven by shocks rather than pre-determined price adjustments) becomes prominent. Davies (2021) examined a large-scale micro-dataset of 41 million UK consumer prices to provide monthly facts on price-setting behaviour over the period 1988–2020, a sample period with a volatile economic environment including the Exchange Rate Mechanism (ERM) crisis, the 2008 GFC and the 2016 EU referendum, as well as the coronavirus pandemic. They found that state-dependent models, rather than time-dependent pricing models, were consistent with the behaviour of UK firms. Regarding pricing, the coronavirus pandemic had a more severe impact than the GFC, with a surge in the frequency of price change including both upward and downward price movements.

With respect to state-dependent wage adjustments, there is a relatively limited number of studies investigating this compared to the literature on state-dependent pricing. Sigurdsson and Sigurdardottir (2016) examined administrative microdata from the Icelandic labour market over the period 1998–2010. They found evidence of time-dependent wage changes and also strong evidence of state-dependence, as the timing of wage adjustments was determined by both cumulated inflation and unemployment over current and past wage spells, in addition to an increase in the frequency of nominal wage cuts following large macroeconomic shocks. Consistent evidence has been found by Grajales et al. (2019), who studied administrative data at the employee level over the period 2006–2021 for the Netherlands and showed a mixture of time- and state-dependent wage behaviour, with inflation and unemployment being important determinants of the probability of wage adjustment. Grigsby et al. (2021) used US microdata from 2008 to 2016 and found strong evidence of downward nominal base wage rigidity for employees who continuously worked for the same firm (referred to as job-stayers), with the nominal base wage duration being around six quarters. They documented time-dependent wage adjustments, with most adjustments occurring one year after the last adjustment. However, they also emphasized evidence of state-dependence, as 6% of workers experienced nominal base wage cuts during the Great Recession, although wage cuts were extremely rare for job-stayers. Their findings suggested that any model with a fixed wage adjustment would struggle to match the patterns of wage setting during severe business cycles. Cajner et al. (2020) investigated the behaviour of the US labour market in the first four months of the coronavirus pandemic and demonstrated that wage adjustments during the pandemic were large relative to the prior recessions. Concerning the UK, the labour market is flexible compared to most other European countries (Millard and Tatomir, 2015), and exhibits a low degree of both downward nominal and real wage rigidity (Dickens et al., 2007). Millard and Tatomir (2015) conducted a wage-setting survey over the period 2010–2013 for the UK and found that the median frequency of wage-setting was once a year and that around 30% of firms directly and explicitly linked wage changes to inflation.

The abundant micro-level evidence on state-dependence has motivated recent macrolevel studies to attempt to replicate this state-dependence using macroeconomic models. Gasteiger and Grimaud (2020) constructed an NK model with a state-dependent price-setting framework in which the decisions to change prices depend on expected costs and benefits; hence a firm will adjust its price optimally only when its expected benefits outweigh its expected costs. They found that the augmented NK model was consistent with price setting frequency based on microdata and can explain the dynamics of inflation to a significant extent. Moreover, their state-dependent framework improved the macroeconomic time series fit of the NK model for the US sample period 1959–2019. However, they only included state-dependent pricing and assumed time-dependent wage setting. According to Sigurdsson and Sigurdardottir (2016) and Costain et al. (2019), a model that incorporates state-dependent price setting but maintains time-dependent wage setting may not accurately measure the impact of monetary changes on real variables and may lead to false conclusions. To the best of our knowledge, only a limited number of studies have included both state-dependent price adjustment and state-dependent wage adjustment within DSGE models, and they all focused on the US, see Takahashi (2018), Costain et al. (2019, 2022) and Le et al. (2021).

Takahashi (2018) developed a DSGE model that incorporates state-dependence in both prices and wages. In this model, the state-dependent pricing framework is based on the stochastic menu cost model of Dotsey et al. (1999). The state-dependent wage setting is endogenously subject to fixed wage adjustment costs that are stochastic and heterogeneous across households, hence endogenously generating staggered nominal wage adjustments. Takahashi (2018) calibrated the distribution of wage setting cost to match the US data on the proportion of wages that remained unchanged for a year and found that the state-dependent wage setting model produced responses to monetary shocks similar to those from the time-dependent model. Costain et al. (2019, 2022) investigated a DSGE model that incorporates state-dependent price/wage setting based on a control cost model, where price and wage decisions are costly and random variables. Price/wage setters are assumed to be subject to control costs and make optimal decisions about when and how to reset their prices/wages. The cost increases with the precision of price/wage decisions. By calibrating the microdata evidence of the frequency of price/wage changes in the DSGE model, where durations depend on inflation, they found that sticky wages play a critical role in the effects of monetary policy on output, as the version of their model exclusively including sticky wages can generate almost as much in the way of output effects as the version with both wage and price stickiness. Furthermore, the model with both sticky prices and wages had a larger real effect of monetary shocks than the model with only price stickiness. According to Le et al. (2021), the studies by Takahashi (2018) and Costain et al. (2019, 2022) used microdata from a stable inflation sample period – the Great Moderation. This may be why their macro models turn out to be similar to the US model of Smets and Wouters (2007).

Le et al. (2011) estimated a hybrid DSGE model for the US with fixed price/wage durations using the Indirect Inference method and found that the model fitted the behaviour of the data for 1984–2004, it was rejected by the data behaviour for the whole post-war period 1947–2004. Le et al. (2021) suggested that the failure of their fixed-duration model to pass the test for the full post-war sample may be attributed to changes in wage/price-setting behaviour over time in response to fluctuations in the macro environment; in particular, there were several significant inflationary episodes during the sample period. Therefore, the authors extended the model to include state-dependence in price/wage durations and re-estimated the model for the full post-war period. Their findings suggest that the model with this extension can match the data behaviour well for the full sample period. Furthermore, they found strong NK periods during the Great Moderation, with more flexible price periods during the Great Inflation and the Great Recession.

The incorporation of state-dependence in macroeconomic models marks a significant departure from traditional models, introducing complexities into the policy implications which we go on to explore in the final section of this paper. Empirical evidence emphasises the effectiveness of QE in enhancing output and inflation during ZLB periods. Studies utilising DSGE models, such as those by Falagiarda (2014) and Lyu et al. (2023), confirm QE's positive impacts in the UK. However, state-dependence poses challenges to QE's ability to control inflation volatility, as shown by Le et al. (2021). Theoretically, conventional monetary policy struggles to stabilise inflation during ZLB periods, leading to increased price duration volatility, which in turn exacerbates price and inflation volatility. As a result, ZLB events in state-dependent models trigger significant fluctuations in inflation. Given the limitations of QE in state-dependent models during ZLB periods, our study explores the welfare effects of implementing a ZLB-suppressing fiscal rule.

Furthermore, there is growing interest in Nominal GDP targeting as a potential alternative to traditional monetary policy frameworks. A Nominal GDP level target rule combines a stronger response to the output gap with a price level target. The first implies more output stability, and the second produces a more persistent response of interest rates to inflation shocks as the price level returns to its target level. This mechanism provides a forward guidance effect and is stronger in stabilising inflation, thereby avoiding the ZLB, as supported by empirical studies such as Le et al. (2016a; 2024). Increasing empirical evidence suggests that a Nominal GDP targeting rule may outperform inflation targeting (Beckworth and Hendrickson, 2020; Billi, 2020; Le et al., 2021, 2023). However, despite this growing evidence, research on Nominal GDP targeting within state-dependent DSGE models remains scarce, pointing to a significant gap in the literature. Therefore, our study goes on to assess the effectiveness of a Nominal GDP targeting rule combined with a fiscal ZLB-suppression policy to explore alternative policy regimes.

Motivated by both micro- and macro-level evidence of state-dependence, this paper investigates state-dependence at the macro-level in the open UK economy by incorporating a state-dependent price/wage contract framework into an open economy DSGE model of the UK, and estimating and testing the model on UK data using the Indirect Inference method. To the best of our knowledge, this is the first empirical study to include both state-dependent price and wage settings in an open economy DSGE model. Furthermore, this study assesses the policy implications of our estimated model and in particular the effectiveness of combining a Nominal GDP targeting rule with a fiscal ZLB-suppression policy. The contribution of this paper is therefore twofold: firstly, it provides macro-level evidence to corroborate the various micro-level evidence of state-dependence in the UK; secondly, it investigates the policy implications of a state-dependent macroeconomic model.

## 3. Model

This model section can be divided into two parts. First, we present an open economy DSGE model with fixed shares of sticky and flexprice sectors in Sections 3.1–3.7, which is the basis for the state-dependent model.[1] Second, we incorporate a state-dependent price/wage contract duration framework into the model in Section 3.8.

The model consists of two blocks. First, a home country (UK) block building on Le et al. (2021), which extends the Smets and Wouters (2007) model by combining the NK and NC models into a hybrid model, adds the BGG banking sector, includes QE and policy regime switching – with or without the ZLB – to incorporate monetary developments following the GFC, and embeds a state-dependent price/wage setting. Second, a simple world block, in the spirit of Gali and Monacelli (2005) and Lyu et al. (2023), introduces exchange rates, foreign bonds, exports and imports. This implies a distinction between the CPI and the home produced goods price index. Furthermore, trade is treated as in the Armington (1969) model. The capital account of the balance of payments operates based on the UIP assumption between domestic and foreign bonds. It is assumed that this small open economy has a negligible effect on foreign variables; hence foreign interest rates and prices are considered as exogenous.

### 3.1. Households

Households face two optimisation problems. First, they are expected to choose consumption and leisure to maximise their utility subject to budget constraints. Second, they choose between domestic and imported goods to maximise the utility of their consumption basket.

#### 3.1.1. Households' lifetime utility maximisation

There is a continuum of households, indexed by $j$, who choose their level of consumption $C_t(j)$, working hours $L_t(j)$, foreign bonds $B_t^f(j)$ and domestic bonds $B_t(j)$ holdings to maximise the following utility function:

$$\max_{C_t,L_t,B_t,B_t^f} E_t \sum_{s=0}^{\infty} \beta^s \left( \frac{\left(C_{t+s}(j) - hC_{t+s-1}\right)^{1-\sigma_c}}{1-\sigma_c} \right) exp\left( \frac{\sigma_c - 1}{1+\sigma_l} L_{t+s}(j)^{1+\sigma_l} \right) \tag{1}$$

subject to the real term budget constraint

[1] Lyu et al. (2023) estimated and tested a UK DSGE model with fixed price/wage contracts and found that their model can match the behaviour of data from 1993 to 2016. Our work here enriches their UK model by distinguishing between domestic and CPI prices as well as between real consumer and real producer wages and, in particular, by incorporating price/wage state-dependence, to investigate whether the model can match our long sample period marked by significant economic fluctuations.

$$C_{t+s}(j)+\frac{B_{t+s}(j)}{\varepsilon_{t+s}^{b}(1+R_{t+s})P_{t+s}}+\frac{S_{t+s}B_{t+s}^{f}(j)}{\varepsilon_{t+s}^{b}(1+R_{t+s}^{f})P_{t+s}}+Tax_{t+s}\leq\frac{W_{t+s}(j)L_{t+s}(j)}{P_{t+s}}+\frac{B_{t+s-1}(j)}{P_{t+s}}+\frac{S_{t+s}B_{t+s-1}^{f}(j)}{P_{t+s}}+\frac{Div_{t+s}}{P_{t+s}} \tag{2}$$

Where $\beta$ is the discount factor, $h$ captures external habit formation, $\sigma_c(\sigma_l)$ is the inverse of the intertemporal substitution elasticity between consumption (labour hours), $P_t$ is CPI, $S_t$ is the nominal exchange rate, $R_t$ and $R_t^f$ are nominal riskless rates on domestic and foreign bonds respectively. All households are assumed to face the same budget constraint in each period. At time t, each household receives a nominal wage $W_tL_t$ by supplying labour, dividends $Div_t$ distributed from labour unions and returns from the past position in bonds holdings. Their total income is used to consume $C_t$, re-invest in domestic and foreign bonds, and pay a lump sum tax $Tax_t$. $\varepsilon_t^b$ is an AR(1) preference shock in financial assets, which is subject to both domestic and foreign bonds.

The households' first order conditions for $C_t$ and $B_t$ imply the consumption Euler equation:

$$E_t\left[\beta\frac{(C_{t+1}-hC_t)^{-\sigma_c}exp\left(\frac{\sigma_c-1}{1+\sigma_L}L_{t+1}^{1+\sigma_L}\right)}{(C_t-hC_{t-1})^{-\sigma_c}exp\left(\frac{\sigma_c-1}{1+\sigma_L}L_t^{1+\sigma_L}\right)}(1+R_t)\varepsilon_t^b\frac{P_t}{P_{t+1}}\right]=1 \tag{3}$$

The first order condition for $L_t$ gives the marginal rate of substitution between working and consumption, which is the real wage desired by the households:

$$\left(\frac{(C_t-hC_{t-1})^{1-\sigma_c}}{1-\sigma_c}\right)(\sigma_c-1)L_t^{\sigma_L}\exp\left(\frac{\sigma_c-1}{1+\sigma_L}L_t^{1+\sigma_L}\right)=-\lambda_t\frac{W_t}{P_t} \tag{4}$$

By combining the first order conditions for $B_t$ and $B_t^f$, we obtain the Uncovered Interest Rate Parity (UIP) condition:

$$\frac{1+R_t^f}{(1+R_t)S_t}=\frac{1}{E_tS_{t+1}} \tag{5}$$

While some negative empirical evidence exists on the UIP condition, it is supported by recent empirical studies with data from different countries, including the UK, see Minford et al. (2021) and Minford et al. (2022). They found that UIP is generally accepted as part of a full-world DSGE model and suggested that previous evidence of UIP rejection may be attributed to bias in single-equation regression tests.

### 3.1.2. Optimal consumption basket

This small open economy model assumes that trade is broadly treated as in the Armington (1969) model. Our Armington aggregator demonstrates that there is an all-purpose home good and an all-purpose foreign good, differentiated according to their country of origin, and combined to form a consumer bundle. Notice that the Armington procedure aggregates home and foreign contributions to final consumption, which are traded, and how these are assumed to break down in detail is not detailed. Different ways of assuming how this detail is achieved are consistent with the procedure. Our Armington consumption aggregator has the form of[2]:

$$C_t\equiv\left[(1-\omega)^{\frac{1}{\sigma}}\left(C_t^d\right)^{\frac{\sigma-1}{\sigma}}+\omega^{\frac{1}{\sigma}}\left(\varepsilon_t^{im}\right)^{\frac{1}{\sigma}}\left(C_t^{im}\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \tag{6}$$

Where $C_t^d$ and $C_t^{im}$ are the indices for consumption of domestically produced goods and imported goods, respectively. $\omega$ is the weight on imported goods in the bundle, $(0<\omega<1)$. $\varepsilon_t^{im}$ is a shock to the demand for imported goods and can be viewed as a preference error. $\sigma$ is the elasticity of substitution between domestic and imported varieties of goods.

The CPI price index is defined as $P_t\equiv\left[(1-\omega)\left(P_t^d\right)^{1-\sigma}+\omega\left(P_t^f\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$, where $P_t^d$ and $P_t^f$ are price indices for domestically produced goods and imported goods in domestic currency, respectively. We assume that the law of one price holds, implying that $P_t^f=S_tP_{f,t}^*$, where $P_{f,t}^*$ is the foreign price index of imported goods in foreign currency. Households' optimal consumption basket problem is to decide how the consumption bundle should be split between domestic and foreign varieties to maximise the Armington consumption

[2] This bundle can take a variety of forms, such as differing combinations of outputs used as inputs to a final good together with home distributive service output.

utility subject to the expenditure constraint of $C_t = p_t^d C_t^d + Q_t C_t^{im}$, where $p_t^d \equiv P_t^d / P_t$ is the domestic price relative to the general price level. $Q_t$ can be seen as a unit-free measure of foreign price in domestic currency relative to the domestic general price level.[3] Intuitively, a rise in $Q_t$ can be seen as a real exchange rate depreciation, as it implies a real devaluation of domestic goods and an increase in the competitiveness of domestic exports. The Armington utility maximisation problem yields the following demand functions:

$$C_t^d = (1-\omega)\left(p_t^d\right)^{-\sigma} C_t \tag{7}$$

$$C_t^{im} = \omega (Q_t)^{-\sigma} C_t \varepsilon_t^{im} \tag{8}$$

Where Eq. (8) is the demand for imports, $IM_t$; $IM_t = C_t^{im} = \omega(Q_t)^{-\sigma} C_t \varepsilon_t^{im}$. By symmetry, the demand for exports is:

$$EX_t = \omega^f (Q_t)^{\sigma^f} C_t^f \varepsilon_t^{ex} \tag{9}$$

Where $f$ is the foreign country index. Foreign consumption $C_t^f$ is assumed to be an exogenous AR(1) process.[4] We assume that there is no capital control; the balance of payments constraint is expressed as:

$$B_{t+1}^f - B_t^f = R_t^f B_t^f + \frac{p_t^d EX_t}{Q_t} - IM_t \tag{10}$$

Domestic Inflation and CPI inflation

Following Gali and Monacelli (2005), by combining the log-linearised form of the effective terms of trade, $tot_t = p_{f,t} - p_{d,t}$, and the log-linearised CPI, $p_t \equiv (1-\omega)p_{d,t} + \omega p_{f,t}$, a relationship between home inflation and CPI inflation can be derived as:

$$\pi_t^{cpi} = \pi_t^h + \omega \Delta tot_t \tag{11}$$

Where $tot_t$ is terms of trade, $\pi_t^{cpi}$ is CPI inflation and $\pi_t^h$ is domestic inflation.

Assuming that the law of one price holds at all times, a relationship between the real exchange rate and the terms of trade can be derived, as in Gali and Monacelli (2005):

$$tot_t = \frac{1}{1-\omega} q_t \tag{12}$$

By substituting Eq. (12) into Eq. (11), we obtain an expression for CPI inflation in terms of domestic inflation and the percent change in the real exchange rate, in log-linearised form:

$$\pi_t^{cpi} = \pi_t^h + \frac{\omega}{1-\omega} \Delta q_t \tag{13}$$

This equation makes the gap between the two measures of inflation proportional to the percentage change in the real exchange rate.

The difference between CPI and the price index of domestically produced goods implies a wedge between the real consumer wage and the real producer wage; its log-linearised form is:

$$w_t^h = w_t^c + \frac{\omega}{1-\omega} q_t \tag{14}$$

Where $w_t^h$ is the real producer wage, $w_t^c$ is the real consumer wage.

### 3.2. *Intermediate labour unions – hybrid wage setting*

We follow Le et al. (2011, 2016a, 2021) in applying a hybrid wage setting, i.e., a fraction of labour markets $(\omega_w)$ are assumed to be imperfectly competitive with wage rigidity, similar to the NK model; whereas the remainder $(1-\omega_w)$ are perfectly competitive with wage flexibility, similar to the NC model. For the NC version wage $\left(W_t^{NC}\right)$, it is set equal to the current expected marginal disutility of work. For the NK version, we assume that labour unions set wages according to the Calvo wage-setting rule. In each period, a fraction of labour unions $(1-\xi_w)$ have the opportunity to re-adjust wages and therefore choose an optimal wage $(W_t^{\#}(l))$, while the remaining unions $(\xi_w)$ cannot adjust their wages and therefore set wages with partial indexation to the CPI inflation rate in the previous period

[3] The consumption constraint, $P_t C_t = P_t^d C_t^d + P_t^f C_t^{im}$, can be rewritten as $C_t = (P_t^d/P_t) C_t^d + \left(S_t P_{f,t}^* / P_t\right) C_t^{im} \cong (P_t^d/P_t) C_t^d + (S_t P_t^*/P_t) C_t^{im} = p_t^d C_t^d + Q_t C_t^{im}$, as $P_t^* \cong P_{f,t}^*$ (it is assumed that exports from the UK have negligible impact on the rest of the world), where $P_t^*$ is the general foreign price index and $Q_t$ is the real exchange rate. This formulation of the consumption constraint is also used by Meenagh et al. (2010), Dong et al. (2019), Minford and Meenagh (2020) and Lyu et al. (2023).

[4] It is worth noting that this small open economy model simplifies the foreign sector by treating foreign consumption and foreign interest rates as exogenous AR(1) processes, given the primary focus of this study is on state-dependence. In reality, global shocks and international spillovers may play a stronger role in shaping UK macroeconomic dynamics, especially in the period following the 2008 financial crisis. Extending the model to explicitly incorporate these international interactions and spillover channels would provide a valuable direction for future research.

and the steady state value. The NK version of the aggregate wage index $\left(W_t^{NK}\right)$ is expressed as:

$$W_t = \left[\xi_w\left[\left(\gamma\left(\pi_{t-1}^{cpi}\right)^{l_w}\left(\pi_*^{cpi}\right)^{1-l_w}\right)W_{t-1}(l)\right]^{1-e_{w,t}} + (1-\xi_w)W_t^{\#}(l)^{1-e_{w,t}}\right]^{\frac{1}{1-e_{w,t}}} \tag{15}$$

Where $l_w$ is the partial wage indexation coefficient.

The hybrid wage setting is assumed to be a weighted average of the corresponding NK and NC equations:

$$W_t^{\text{hybrid}} = \omega^w W_t^{NK} + (1-\omega^w)W_t^{NC} \tag{16}$$

### 3.3. Final goods producers – hybrid price setting

Final goods producers combine the intermediate goods sold in imperfectly competitive markets with those sold in perfectly competitive markets to produce final goods. As in Le et al. (2011, 2016a, 2021), it is assumed that the intermediate goods producers supply intermediate goods at prices determined partly in imperfectly competitive markets and partly in perfectly competitive markets. Therefore, the hybrid price equation is $\left(P_t^d\right)^{\text{hybrid}} = \omega^p\left(P_t^d\right)^{NK} + (1-\omega^p)\left(P_t^d\right)^{NC}$, where $\omega^p$ is the fraction of intermediate goods sold in imperfectly competitive markets, $\left(P_t^d\right)^{NK}$ is set according to the Calvo rule and $\left(P_t^d\right)^{NC}$ is the marginal cost. They are derived in the subsequent section.

### 3.4. Intermediate goods producers and commercial banks

We incorporate a modified BGG financial friction into the model, which allows for the effects of QE. Firms purchase newly installed capital from capital producers for intermediate goods production. Capital expenditures are financed by firms' net worth and external loans from commercial banks. Therefore, firms' activities determine the production of intermediate goods, the level of capital utilisation, loan contracts and net worth.

#### 3.4.1. Production of intermediate goods

A representative firm uses labour and effective capital $\left(K_t^s\right)$ inputs to produce intermediate goods and it follows the Cobb-Douglas technology:

$$Y_t(i) = \varepsilon_t^a K_t^s(i)^{\alpha}\left[\gamma^t L_t(i)\right]^{1-\alpha} - \gamma^t\phi \tag{17}$$

Where $i$ is the intermediate goods sector index, $\alpha$ is the share of capital in the production, $\phi$ is one plus the fixed costs in production, $\gamma^t$ is the labour-augmenting deterministic growth rate in the economy, $\varepsilon_t^a$ is total factor productivity it is assumed to be nonstationary and follow an ARIMA $(1,1,0)$ process. The firm purchases capital and chooses an optimal level of capital utilisation $Z_t$. Thus, the amount of effective capital is $K_t^s(i) = Z_t(i)K_{t-1}(i)$. The optimal capital utilisation is $R_t^K = \psi'(Z_t)$, where $\psi'(Z_t)$ is the first order derivative of the adjustment cost of capital utilisation. The firm chooses the amount of effective capital and labour inputs to maximise profit. The optimal conditions give the real marginal cost and the real capital-labour ratio:

$$MC_t = \frac{\left(R_t^k\right)^{\alpha}\left(\frac{W_t}{P_t^d}\right)^{1-\alpha}}{\varepsilon_t^a(1-\alpha)^{1-\alpha}\alpha^{\alpha}} \tag{18}$$

$$K_t^s = \frac{\alpha}{1-\alpha}\frac{\left(\frac{W_t}{P_t^d}\right)}{R_t^k}L_t \tag{19}$$

Where $W_t/p_t^d$ is the real producer wage.

It is assumed that a fraction of goods markets set prices flexibly as in the NC model, while the rest have sticky prices as in the NK model. In the NC version, firms set the domestic price equal to the marginal cost, Eq. (18). For the NK version, each firm is subject to nominal rigidities according to the Calvo model. In each period, a fraction of firms, $\left(1-\xi_p\right) \in [1,0]$, can choose an optimal domestic price $\left[P_t^d(i)\right]^{\#}$, while the remainder cannot re-optimise their prices and thus set prices according to the partial indexation rule, $P_t^d(i) = \left(\pi_{t-1}^h\right)^{l_p}\left(\pi_*^h\right)^{1-l_p}P_{t-1}^d(i)$, where $l_p$ is the partial price indexation coefficient. Thus, the aggregate domestic price in the imperfectly competitive market evolves according to:

$$P_t^d = \left[\xi_p\left[\left(\pi_{t-1}^h\right)^{l_p}\left(\pi_*^h\right)^{1-l_p}P_{t-1}^d(i)\right]^{1-\varrho_{p,t}} + (1-\xi_p)\left(\left[P_t^d(i)\right]^{\#}\right)^{1-\varrho_{p,t}}\right]^{\frac{1}{1-\varrho_{p,t}}} \tag{20}$$

#### 3.4.2. Financial friction and the role of QE

In the BGG model, at time t, firms purchase newly installed capital $(K_{t+1})$ from capital producers at price $\left(P_t^k\right)$ for production in period t+1. In period t+1, firms obtain revenue from the marginal product of capital $\left(R_{t+1}^k\right)$ and gain from selling undepreciated capital $(1-\delta)$ to capital producers at price $P_{t+1}^k$. In equilibrium, the capital arbitrage condition implies:

$$E_t(CY_{t+1}) = E_t\left[\frac{R_{t+1}^k + (1-\delta)P_{t+1}^k}{P_t^k}\right] \tag{21}$$

Where $CY_{t+1}$ is the expected marginal rate of real return on capital.

Firms finance their capital purchases with net worth and external loans from commercial banks. Financial frictions evolve from information asymmetries between lenders and borrowers. The lender faces a 'Costly State Verification' problem and must pay a monitoring cost to observe the borrower's realised return on capital. This cost can be viewed as the cost of bankruptcy.

In the BGG model, firms do not provide collateral. To allow for the effects of QE, we follow Le et al. (2016a) and extend the BGG model by assuming that banks require firms to provide a certain amount of collateral ($c$) as part of their net worth. The cost of recovering this collateral is a percentage ($\delta$) of its initial value; $\delta$ corresponds to the depreciation rate in the SW07 model. We assume that firms hold cash as cheap collateral as it can be recovered directly without liquidation costs and loss of value. In times of crisis, we assume that the central bank issues cash M0 to households through QE in exchange for the bonds they hold, and households have no need for M0 and will deposit all of it with commercial banks, which then lend it to the firms to hold as collateral. Therefore, an increase in the supply of M0 will translate into a lower credit premium, resulting in a lower commercial lending rate. The model captures the impact of M0 on the credit premium through its impact on the cost of liquidating collateral ($\delta$), following Le et al. (2016a), the log-linearized form is:

$$prem_t = E_t cy_{t+1} - \left(r_t - E_t\pi_{t+1}^{cpi}\right) = \chi(qq_t + k_t - n_t) - \vartheta m_t^0 + \varepsilon_t^{prem} \tag{22}$$

Where $qq_t$ is the price of capital, $n_t$ is net worth, $\chi$ is the elasticity of the external finance premium with respect to the leverage ratio, $\vartheta$ is the elasticity of the premium to M0 through its collateral role, $\varepsilon_t^{prem}$ is an exogenous premium shock. This equation shows that monetary policy can affect the risk premium on bank lending to firms by adjusting the supply of M0.

#### 3.4.3. Net worth

We assume that the probability of a firm surviving to the next period is $\theta$, and the net worth of surviving firms carried over from the previous period is given by the past net worth $(\theta n_{t-1})$ plus total return on capital $\left(cy_t\right)$ minus the expected return (cost of borrowing paid to the banks):

$$n_t = \frac{K}{N}(cy_t - E_{t-1}cy_t) + E_{t-1}cy_t + \theta n_{t-1} + \varepsilon_t^{nw} \tag{23}$$

where $K/N$ is the steady-state ratio of capital to net worth.

Those firms that exit the market will consume all their net worth. Thus, the consumption of these firms is equal to the probability of dying from the market $(1-\theta)$ multiplied by their net worth. Its logarithmic form is:

$$c_t^e = n_t \tag{24}$$

### 3.5. Capital producers

At the end of each period, capital producers buy existing capital $(1-\delta)K_{t-1}$ from intermediate goods producers and combine it with investment $(I_t)$ to produce new capital $(K_t)$. The capital producers' problem is to choose the level of investment that maximises their expected discounted profit, i.e., $max_{I_t} E_t\sum_{t=0}^{\infty}\beta^t\lambda_t\left[P_t^k(K_t-(1-\delta)K_{t-1}) - I_t\right]$ subject to the capital accumulation equation, $K_t = (1-\delta)K_{t-1} + \varepsilon_t^i[1-S(I_t/I_{t-1})]I_t$, where $\delta\in(0,1)$ is the depreciation rate, $S(\cdot)$ is the investment adjustment cost function as in SW07, $\varepsilon_t^i$ is the investment-specific shock, following an AR (1) process.

### 3.6. Monetary and fiscal policies

#### 3.6.1. Monetary policy

This subsection follows Le et al. (2016a) in presenting monetary policy separately within normal and crisis regimes, as monetary policy tools differ in crisis and non-crisis times. The monetary policy in the crisis regime incorporates new developments that have emerged since the onset of the recent GFC, including the ZLB and the implementation of QE.

**In a normal regime** (quarterly $r_t > 0.025\%$), the central bank conducts conventional monetary policy according to the Taylor Rule. The supply of M0 is set to accommodate broad money M2, which is set equal to M0 plus deposits from households. Deposits are set equal to the number of loans lent to firms, which is equal to total capital expenditure minus net worth, $deposits = borrowing = capital\ expenditure - net\ worth$. Thus, we have $M2 = capital\ expenditure - net\ worth + M0$. The monetary policy framework under the normal regime is summarised as follows:

$$\text{For } r_t > 0.025\% \begin{cases} r: & r_t = \rho r_{t-1} + (1-\rho)\left(r_p \pi_t^{cpi} + r_y y_t\right) + r_{\Delta y}(y_t - y_{t-1}) + \varepsilon_t^r \\ M0: & m_t^0 = m_{t-1}^0 + \vartheta_1\left(m_t^2 - m_{t-1}^2\right) + \varepsilon_t^{m0,nocrisis} \\ M2: & m_t^2 = (1+\nu-\mu)k_t + \mu m_t^0 - \nu n_t, \nu = \dfrac{N}{M2}, \mu = \dfrac{M0}{M2} \end{cases} \tag{25}$$

Where $\rho$ reflects the degree of interest rate smoothing. $r_p, r_y$ and $r_{\Delta y}$ measure the response to inflation, output and output gap, respectively. $\nu = N/M2$ and $\mu = M0/M2$ are the steady-state ratio of net worth to $M2$ and the steady-state ratio of $M0$ to $M2$ respectively. $\vartheta_1$ is the elasticity of $M0$ to $M2$.

**In a crisis regime** (where quarterly $r_t \leq 0.025\%$), the bank rate is at or below the lower bound, indicating that the conventional tool reaches its limit. Therefore, we suspend the Taylor Rule and replace it with an exogenous low bound ($r_t = 0.025\%$). In addition, the central bank turns to unconventional monetary policy. QE is activated and M0 becomes the primary tool to target credit markets with the aim of reducing the risk premium on given leverage and boosting credit supply. Once the model moves away from the lower bound at some point, the Taylor Rule will be operative again. The monetary policy under the crisis regime is summarised as:

$$\text{For } r_t \leq 0.025\% \begin{cases} M0: & m_t^0 = m_{t-1}^0 + \vartheta_2(prem_t - prem^*) + \varepsilon_t^{m0,crisis} \\ r: & r = 0.025\% \end{cases} \tag{26}$$

where $\vartheta_2$ is the elasticity of M0 with respect to premium, and $prem^*$ is the steady-state credit premium. The mechanism works as follows: the more significant the credit spread, the more effort is required to stabilise the credit premium through M0 injection.

### *3.6.2. Fiscal policy*

The government budget constraint takes the form of $P_t G_t + B_{t-1} = T_t + B_t/R_t$. Government spending ($G_t$) is exogenously determined as a time-varying component relative to the steady-state output path, $\varepsilon_t^g = G_t/Y\gamma^t$, where $\varepsilon_t^g$ is the government spending shock affecting the amount of government spending relative to GDP, which is modelled as an $AR(1)$ process and is also affected by productivity shocks, $\varepsilon_t^g = \rho_g \varepsilon_{t-1}^g + \eta_t^g + \rho_{ga}\eta_t^a$.

## *3.7. Market clearing conditions*

The log-linearised aggregate resource constraint for the economy combined with $\varepsilon_t^g = G_t/Y\gamma^t$ is given by:

$$y_t = \frac{C}{Y}c_t + \frac{I}{Y}i_t + R_*^K k_y \frac{1-\psi}{\psi} rk_t + \frac{C^e}{Y}c_t^e + \frac{EX}{Y}ex_t - \frac{IM}{Y}im_t + \varepsilon_t^g \tag{27}$$

Where $\frac{C}{Y}, \frac{I}{Y}, R_*^K k_y, \frac{C^e}{Y}, \frac{EX}{Y}$ and $\frac{IM}{Y}$ are steady-state ratios.

Given that the goods markets clear and income can only be spent on goods or assets, it implies that all asset markets must also clear. According to Minford and Meenagh (2020), at some terminal date T, the real exchange rate is constant, thus the change in net foreign assets is zero; the real exchange rate is constrained by terminal conditions to ensure that the current account is balanced in the long run.

The balance of payments is subject to a constraint imposed by the transversality condition, i.e. the change in net foreign assets (the capital account) must be zero in the long-run. At the terminal date T, the equilibrium real exchange rate remains constant, the cost of servicing the current debt is covered by an equivalent trade surplus:

$$R_T^f B_T^f = -\left(\frac{p_T^d EX_T}{Q_T} - IM_T\right) \tag{28}$$

The terminal condition serves to ensure that the transversality condition is satisfied. The numerical solution path must be consistent with the constraint it imposes on the rational expectations. When solving the model, the balance of payments constraint is scaled by output, enabling the terminal condition to impose a constant ratio of net foreign assets to GDP in the long-run, $\Delta\widehat{B}_{t+1}^f = 0$ as $t \to \infty$, where $\widehat{B}_{t+1}^f = B_{t+1}^f / Y_{t+1}$.[5]

[5] The model is solved under rational expectations using the projection method outlined by Fair and Taylor (1980) and Minford et al. (1984, 1986). At the terminal date T, the expectations must meet the terminal conditions of the model. These conditions are imposed to guarantee that the simulated paths of the endogenous variables converge to long-term levels at the terminal date, in line with the long-run implications of the model (Minford et al., 1979). Imposing the terminal conditions on the expectations involves solving the equilibrium system sometime in the future, given that shocks have stopped, the stationary variables have reached their long-run constant values, and the trended variables have maintained a constant growth rate. Additionally, the transversality condition must hold to ensure that the net foreign assets are stable and that net international debt does not grow over time.

### 3.8. State-dependent price/wage contracts

This subsection extends the fixed price/wage contract model built in Sections 3.1–3.7 to include a state-dependent price/wage contract framework. The fixed-duration model assumes that a fixed fraction of goods markets are imperfectly competitive with nominal rigidities, while the rest are perfectly competitive with flexible pricing; the labour market is similar. To embed state-dependent variation, we assume that the fraction of firms with flexible prices and the fraction of unions with flexible wages are state-dependent rather than fixed, and are based on an increasing function of past inflation.

We define the sticky price/wage sectors (or NK sectors) as the long duration sectors because prices/wages are sticky for more than one quarter. On the other hand, the flexible price/wage sectors (or NC sectors) are defined as the short duration sectors because prices/wages constantly change every quarter. In the fixed price/wage duration model, the long duration sectors have fixed weights, i.e., $\omega^w$ and $\omega^p$ are fixed. As a result, the short duration sectors also have fixed weights: $(1-\omega^{w})$ and $(1-\omega^{p})$ are fixed. Furthermore, firms/labour unions change their prices/wages according to the fixed Calvo probabilities. To incorporate state-dependence, we relax the assumption of fixed durations and assume that the structure of the price/wage durations is state-dependent. This implies that firms and labour unions adjust their prices and wages more frequently in response to aggregate shocks and therefore some of them shift from long duration to short duration in this state-dependent model.

We assume that firms' decisions to change their prices depend on the shocks' size. If the shock size is less than the critical shock size, at which the cost of changing prices is equal to the gain from providing insurance to customers, then the choice would be to stabilise prices to ensure customers against uncertainty. However, if the shock size exceeds the critical value, it would then be optimal to update prices and reset them optimally to respond to the shock, as the cost of providing this insurance to customers in this case is greater than the expected benefit. In other words, firms will only adjust prices when the shock is greater than the critical shock size. The wage adjustment framework is similar.

It is assumed that the variance of the idiosyncratic cost-shock distribution used by price setters is state-dependent. More specifically, we assume that it is associated with the size of recent inflation shocks, represented by Π and measured by a moving average of inflation. Therefore, recent inflation shocks to the economy, Π, affect the variance of the cost-shock distribution, which in turn adjusts the weights of sectors with sticky and flexible pricing durations. For example, if there is an increase in recent inflation, it would cause a higher variance of the idiosyncratic cost-shock distribution. The higher variance indicates that the critical shock level occurs at a lower percentile of the distribution, as shown in Fig. 1. A lower percentile means a lower probability of not changing prices, leading to an increased number of sectors adopting flexible pricing. Hence, recent inflation affects the variance of idiosyncratic shock distribution, thereby changing the allocation of weights between sectors with sticky prices and those with flexible pricing. Wage changes are similar.

If recent inflation rises, the Calvo probability of not changing prices consequently decreases, causing more sectors to become flexprice, which may subsequently decrease the Calvo parameters in the remaining sectors (i.e. sticky-price sectors). We describe this as a 'reduction effect' on the Calvo parameters in the remaining sectors. On the other hand, there is an 'abandonment effect', as the sectors closer to the short duration sector would shift to it, leaving those sectors with higher Calvo parameters in the sticky sector. This abandonment effect is contrary to the reduction effect, resulting in the Calvo parameters for the NK sectors potentially increasing, decreasing, or remaining unchanged. Consequently, the Calvo parameters are not estimated to be state-dependent. Instead, they are estimated using the Indirect Inference method, similar to other model parameters, but allowing for this net response to Π.

We use the function proposed by Le et al. (2021) to relate the weights on sticky price and wage sectors to the variance of past inflation:

$$\omega^{i} = \exp\left(-\vartheta^{i}\Pi\right) \tag{29}$$

where $i=p,w$, and Π is the square of the moving average of inflation over the past four years. $\omega^{p}$ and $\omega^{w}$ are proportions of sticky prices and wages, respectively. $\vartheta^{p}$ and $\vartheta^{w}$ are parameter responses of NK weights to the variance of inflation for prices and wages, respectively. $\vartheta^{p}$ and $\vartheta^{w}$ are determined empirically through the Indirect Inference estimation. The weights on the long duration sectors, $\omega^{i}$, are calculated according to Eq. (29); thus, the weights now are state-dependent. This state-dependence is added to the DSGE model. The model is nonlinear as the price/wage parameters change endogenously with inflation shocks.

## 4. Estimation method and data

### 4.1. The method of indirect inference

The model is estimated and tested using a simulation-based Indirect Inference method, which was first introduced by Smith (1993), further developed by Minford et al. (2009) and Le et al. (2011) using Monte Carlo experiments, and extended to test nonstationary data byMeenagh et al. (2012).[6] Indirect means choosing an auxiliary model (e.g. VAR, VARX or VARMA) that is independent of the theoretical model as the lens to generate a description of the data. This is then used to indirectly assess how well the theoretical model performs. This description of the data can be summarised by the estimated parameters of the auxiliary model. Through the Indirect

[6] Indirect Inference has been proven to be a powerful method for testing structural macroeconomic models; see Minford et al. (2009), Le et al. (2010, 2015, 2016b) and Meenagh et al. (2019).

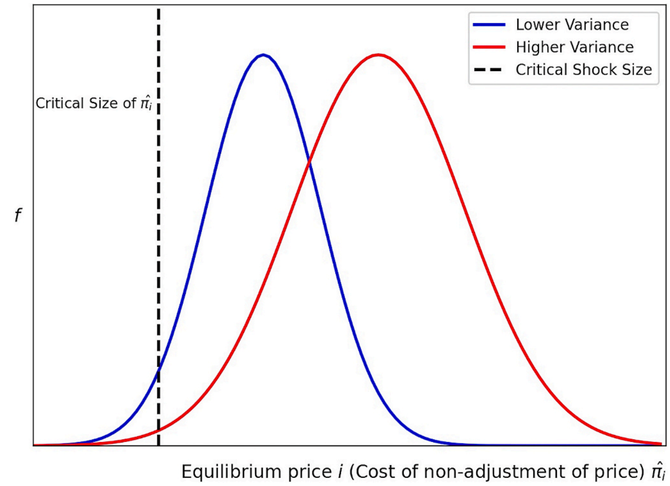


**Fig. 1.** Distribution of Idiosyncratic Shocks.

Inference method, models of any size, complexity and non-linearity can be estimated and tested by comparing the performance of the auxiliary model estimated on simulated data with the performance of the auxiliary model estimated on observed data.

Concerning the computation of state-dependent weights for sticky prices and wages: initially, the model generates data for the first period. Weights are then calculated based on the simulated inflation data and subsequently employed to simulate the next period. This process is repeated for each period, ensuring that the weights are constantly adjusted to reflect changing economic conditions. The procedure for the Indirect Inference test and estimation of state-dependent models is illustrated in Fig. 2.

Regarding the choice of the auxiliary model, we follow Meenagh et al. (2012) and use a VARX to represent our log-linearised model as we have nonstationary data and residuals. The comparison uses a statistical criterion based on a Wald test, which measures the difference between the vector of relevant VARX parameters from simulated and actual data. A correct structural model should generate sensible simulated data and corresponding VARX estimates that are not significantly different from the actual data and their corresponding VARX estimates. Our Wald test is based on three variables because of the 'ideal power' – not so high as to stop a good model from passing, but high enough to reject bad models with high probability. Meenagh et al. (2019) show that using a VAR with three variables (it does not matter which three are chosen) is adequate to provide an indirect test with high power for a large model. However, adding more variables would produce excessive power. A VARX (1) containing our three variables of interest is the basis of the Wald test, which takes the form of:

$$\begin{bmatrix} y_t \\ \pi_t \\ r_t \end{bmatrix} = B \begin{bmatrix} y_{t-1} \\ \pi_{t-1} \\ r_{t-1} \end{bmatrix} + C \begin{bmatrix} T \\ \varepsilon_t^a \\ b_{t-1}^f \end{bmatrix} + \begin{bmatrix} \epsilon_t^y \\ \epsilon_t^\pi \\ \epsilon_t^r \end{bmatrix} \text{ where } B = \begin{bmatrix} \theta_{yy} & \theta_{y\pi} & \theta_{yr} \\ \theta_{\pi y} & \theta_{\pi\pi} & \theta_{\pi r} \\ \theta_{ry} & \theta_{r\pi} & \theta_{rr} \end{bmatrix}$$

Where $T$, $\varepsilon_t^a$ and $b_{t-1}^f$ are the deterministic time trend, the nonstationary residuals and lagged nonstationary foreign assets, respectively.

When testing the model, we simulate the structural model and apply the auxiliary model to each simulated dataset. This gives us a distribution of the auxiliary model parameters. We then compute the Wald statistic to see if the estimates of the auxiliary model obtained from the actual data fall within some confidence interval suggested by this distribution. The Wald statistic is defined as:

$$W = (\beta^\alpha - \overline{\beta^s})' \Omega^{-1} (\beta^\alpha - \overline{\beta^s})$$

Where $\beta$ contains nine coefficients from the matrix $B$ describing the dynamic properties of the model and data, plus the three error variances measuring the size of variation. Thus, $\beta = \begin{bmatrix} \theta_{yy} & \theta_{y\pi} & \theta_{yr} & \theta_{\pi y} & \theta_{\pi\pi} & \theta_{\pi r} & \theta_{ry} & \theta_{r\pi} & \theta_{\pi r} & \text{var}(\epsilon_t^y) & \text{var}(\epsilon_t^\pi) & \text{var}(\epsilon_t^r) \end{bmatrix}'$. $\beta^\alpha$ denotes the estimates of VARX coefficients derived from actual data, and $\overline{\beta^s}$ denotes the mean of their distribution based on the simulated data. $\Omega^{-1}$ is the inverse of the variance–covariance matrix of the distribution of simulated estimates $\beta^s$. We do not reject the null hypothesis that the model is the true model only if it can jointly match the 12 coefficients in $\beta$. A summary of the steps to implement the Indirect Inference Wald test by bootstrapping can be found in Meenagh et al. (2012).

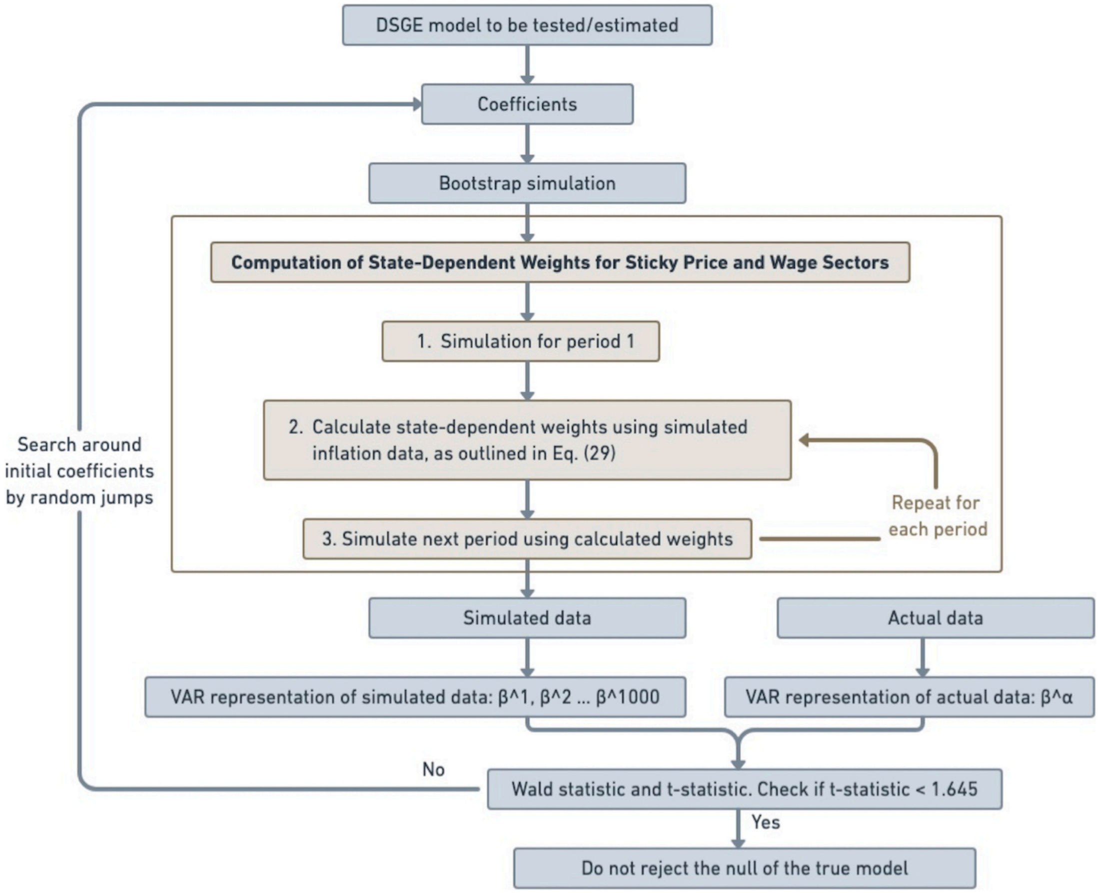


**Fig. 2.** The Procedure for the Indirect Inference Test and Estimation of State-dependent Models.

The optimal parameter set for the structural model is the one that minimises the distance between the VARX estimates based on simulated data and those based on the actual data, as indicated by the minimum Wald statistic – or the minimum t-statistic.[7] To search for the optimal parameter set, we use the Simulated Annealing algorithm, in which a search is conducted over a wide range around initial values by random jumps.

To briefly summarise, Indirect Inference is a simulation-based estimation method that matches key characteristics of the actual data—such as VAR coefficients, impulse response functions, or moments—by simulating the model and comparing it to observed data. According to Meenagh et al. (2019), this ensures the model's overall data behaviour is replicated, a property that Bayesian approaches do not guarantee. Bayesian or Maximum Likelihood estimation typically requires detrending macroeconomic time-series, which may discard important data features, especially in non-stationary series. In contrast, Indirect Inference can estimate models using original, full data, thus preserving its informational richness. Furthermore, Indirect Inference does not rely on prior knowledge of the distribution of the parameters as is needed for Bayesian estimation. In economics, we may lack strong ex-ante information on the likely values of some parameters, so the priors can become arbitrary guesses, heavily influencing the results.

## 4.2. Data

The model was estimated and tested on unfiltered quarterly UK data for 1955Q1-2021Q1.[8] Details of the dataset are provided in Table 1. From October 1949 to May 1972, the UK had a fixed exchange rate regime (or the Bretton Woods system) in which the BoE

[7] The Wald statistic is converted into a normalised t-statistic using $t\_statistic = \left(\frac{\sqrt{2W}-\sqrt{2k-1}}{\sqrt{2W_i^{0.95}}-\sqrt{2k-1}}\right) \times 1.645$, where k represents the number of parameters in $\beta$, $W$ and $W_i^{0.95}$ are Wald statistics for the actual data and 95$^{th}$ percentile of the simulated data, respectively.

[8] The use of filtered data may eliminate or distort the dynamic properties of the model in ways that are not easily detected. Therefore, we use the original data and retain the stochastic trends in the model, as one of our interests is to observe how the behaviour of the stochastic trend is transferred through the model.

**Table 1**
Model variable construction and data sources.

| Variable | Symbol | Definition | Source |
|---|---|---|---|
| Output | $Y$ | $\frac{\text{Gross domestic product : CVM}}{\text{Working population}}$ | ONS |
| Consumption | $C$ | $\frac{\text{Household final consumption expenditure : CVM}}{\text{Working population}}$ | ONS |
| Investment | $I$ | $\frac{\text{Total fixed capital formation : CVM + Changes in inventories : CVM}}{\text{Working population}}$ | ONS |
| CPI Inflation | $\pi^{cpi}$ | Percentage change in CPI | ONS |
| Nominal interest rate | $R$ | $\frac{\text{3 months Treasury Bills rate}}{4}/100$ | OECD and Financial Times |
| Labour hours | $L$ | Average actual weekly hours worked per employee | University of Groningen PWT and ONS |
| Real consumer wage | $W^c$ | $\frac{\text{Wage and salaries}}{\text{Total hours worked * CPI}}$ | ONS |
| External finance premium | $PM$ | $\frac{\text{banking lending rate} - \text{3 month Treasury bills rate}}{4}/100$ | Refinitiv DataStream |
| Real lending rate | $CY$ | $\frac{\text{banking lending rate}}{4*100} - \text{one period ahead CPI inflation}$ | Refinitiv DataStream |
| Net worth | $N$ | $\frac{\text{FTSE all share index}}{\text{CPI}}$ | Refinitiv DataStream |
| M2 | $M2$ | $\frac{\text{M2 money stock, CP}}{\text{CPI *Working population}}$ | FRED, BoE |
| M0 | $M0$ | $\frac{\text{Money supply M0, CP}}{\text{CPI *Working population}}$ | BoE |
| Export | $EX$ | $\frac{\text{Total exports : CVM}}{\text{Working population}}$ | ONS |
| Import | $IM$ | $\frac{\text{Total imports : CVM}}{\text{Working population}}$ | ONS |
| Real Exchange rate | $Q$ | $\frac{1}{\text{Sterling real effective exchange rate index}}$ | BoE, BIS |
| Net foreign bond position | $B^f$ | Current account balance as per cent of GDP | ONS |

*ONS, BoE, FRED, OECD, and BIS are short for the Office for National Statistics, the Bank of England, the Federal Reserve Economic Data, the Organization for Economic Co-operation and Development, and the Bank for International Settlement, respectively.
*CVM: Chained Volume Measure; CP: Current Price.
*Two foreign variables are treated as exogenous AR(1) processes and constructed following Dong et al. (2019): the foreign real interest rate ($r^f$) is the weighted average real interest rates for US (60%), Germany (19%) and Japan (21%); and the foreign consumption demand ($C^f$) is world exports of goods and services.
*The working population is calculated as the sum of "total claimant count (ONS)" and "work force jobs (ONS)".

intervened in the currency market to keep the exchange rate close to the fixed exchange rate target to maintain economic stability. This regime poses a problem for our estimation over the entire sample period of 1955–2021. We address this by adding an exchange rate target to the Taylor Rule (Taylor, 1995) for the period 1955Q1-1972Q2 and turning it into a standard Taylor Rule for the period 1972Q3-2021Q1.

According to Giavazzi and Giovannini (1989), a permanent fixed exchange rate regime differs from a regime where a monetary authority pegs its currency to a numeraire but is free to correct its exchange rate. For the pre-1972 period, under the Bretton Woods system of a fixed-but-adjustable exchange rate, the model treats it as floating with the version of the Taylor Rule with a real exchange rate target included. In other words, the pre-1972 model assumes that a 'fixed' rate is treated as adjustable whenever an adjustment is needed under the Bretton Woods system. Clarida et al. (1998) included the real exchange rate and its target in the Taylor Rules for Italy, France and the UK for the ERM period. Since both the ERM and Bretton Woods system aimed to maintain a fixed-but-adjustable exchange rate regime, we follow them in adding an exchange rate target to the Taylor Rule; see Engel and West (2004), and Wang and Wu (2009) for more examples.

For the post-1972 period, we combine the 1972–1992 floating exchange rate regime and the inflation targeting period 1992–2021, using the standard Taylor Rule without the exchange rate over the whole period. Although the UK is a small open economy, other empirical studies for the UK, including Lyu et al. (2023) using data from 1993 to 2016 and Le et al. (2024) using data from 1986 to 2016, demonstrate that the Taylor Rule without the exchange rate also performs well in terms of data fit. During the earlier 1972–1992 floating period monetary policy was guided solely by domestic considerations, which argues in favour of omitting the exchange rate element; in terms of responses to the domestic elements, the Taylor Rule formulation should be a reasonable approximation to UK policy, much as Taylor (1995) argued it well represented US monetary policy under its floating regime. Hence for the post-1972 period, we do not include the exchange rate in the Taylor Rule - with, as it turns out, successful empirical results.

## 5. Empirical results

Using Indirect Inference estimation, we found that the state-dependent DSGE model can match the dynamic behaviour of the UK data very well over the sample period 1955–2021, with a p-value of 0.087 (see Table 2). It is worth noting that our sample period encompasses a turbulent economic environment, particularly the stagflation of the 1970s. This Great Inflation environment poses a

**Table 2**
Parameter estimates.

| Symbol | Description | Estimates |
|---|---|---|
| Households' parameters | | |
| $\sigma_c$ | Intertemporal elasticity of substitution | 1.6408 |
| $h$ | External habit formation | 0.7016 |
| $\xi_w$ | Elasticity of labour supply | 2.8257 |
| Firms' parameters | | |
| $\varphi$ | Elasticity of capital adjustment | 4.4871 |
| $\psi$ | Elasticity of capital utilization | 0.9485 |
| $\phi$ | 1 + share of fixed costs in production | 1.8837 |
| $\alpha$ | Share of capital in production | 0.5765 |
| The Taylor Rule parameters | | |
| $r_p$ | Taylor Rule response to inflation | 3.1879 |
| $\rho$ | Interest rate smoothing | 0.5769 |
| $r_y$ | Taylor Rule response to output | 0.0172 |
| $r_{\Delta y}$ | Taylor Rule response to change in output | 0.0463 |
| $r_q$ | Taylor Rule response to deviation from real exchange rate target | 0.0445 |
| Financial frictions and money response parameters | | |
| $\chi$ | Elasticity of the premium with respect to leverage | 0.1048 |
| $\vartheta$ | Elasticity of the premium to M0 | 0.0413 |
| $\vartheta_1$ | Money response to credit growth | 0.0692 |
| $\vartheta_2$ | Money response to premium | 0.0700 |
| Price and wage setting parameters | | |
| $\xi_w$ | Probability of not changing wages | 0.6101 |
| $\xi_p$ | Probability of not changing prices | 0.5465 |
| $l_w$ | Wage indexation | 0.3965 |
| $l_p$ | Price indexation | 0.0554 |
| $\vartheta^w$ | Parameter response of NK weight - wages | 105.3684[a] |
| $\vartheta^p$ | Parameter response of NK weight - prices | 93.5372[a] |
| $\omega^w$ | Proportion of sticky wages | State-dependent |
| $\omega^p$ | Proportion of sticky prices | State-dependent |
| Wald $(Y, \pi, R)$ | | 18.3008 |
| P-value | | 0.0870 |
| Transformed T-statistic | | 1.0455 |

[a]It should be noted that Le et al. (2021) transformed their dataset into percentages by multiplying each value by 100, whereas our dataset is not expressed in percentage terms. Therefore, when employing Le et al.'s non-linear function $\omega^i = exp(-\vartheta^i \Pi)$ to our dataset, we use large $\vartheta^p$ and $\vartheta^w$ values to ensure that our time-varying NK weights are broadly in line with theirs.

challenge for models with fixed price/wage durations; we found that such models fail to fit the data over the entire sample period. Our results reinforce the findings of Le et al. (2021) and show that the state-dependent DSGE model is effective in capturing the dynamic behaviour of key macroeconomic variables in the UK for 1955–2021.

The parameter estimates are reported in Table 2. Most of the estimates are close to those of Lyu et al. (2023) for the UK economy and Le et al. (2016a, 2021) for the US economy. Although a few estimates exhibit significant differences from theirs, these are not far from those in the literature as the search range is chosen in line with previous literature.

Figs. 3 and 4 show actual inflation data, the square of MA inflation, and the corresponding state-dependent NK price/wage weights over time. As shown, the NK weights on prices and wages fluctuate between 0.8 and 1, dynamically adjusting to the state of the

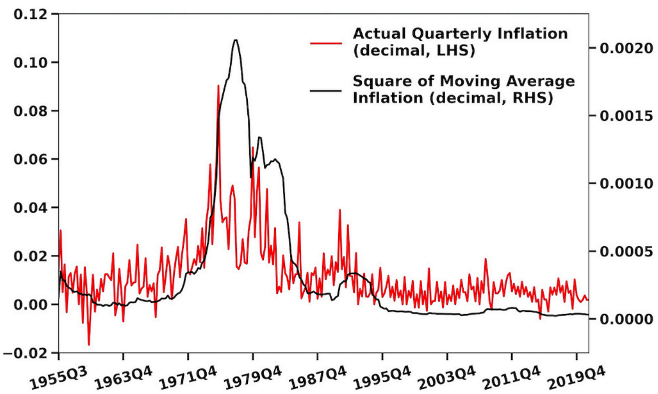


**Fig. 3.** Inflation and the Square of MA Inflation.

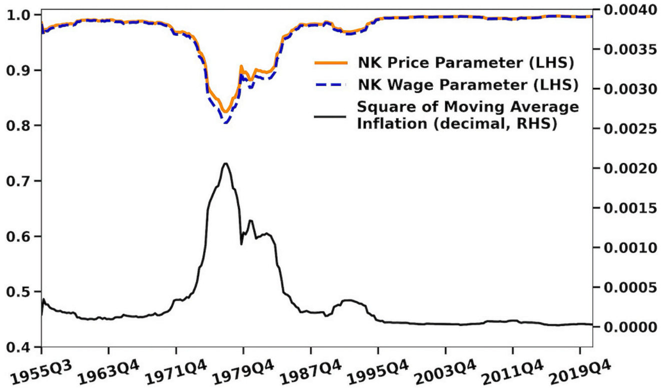


**Fig. 4.** Time Varying NK weights.

economy (inflation). The figures clearly illustrate an inverse relationship between the NK weights and economic conditions: higher inflation corresponds to lower NK weights. For example, during the 1970s, the NK weights fell significantly as inflation surged. In contrast, during the Great Moderation, the NK weights rose to nearly one. This pattern provides evidence supporting the idea that price and wage adjustments are indeed state-dependent and adjust in response to economic fluctuations.

Fig. 5 provides examples of simulations (shown in red) that tend to match the features of the movements in the actual data (shown in blue), hence accounting for the good p-value. The last row of the figure shows the corresponding time-varying NK price/wage

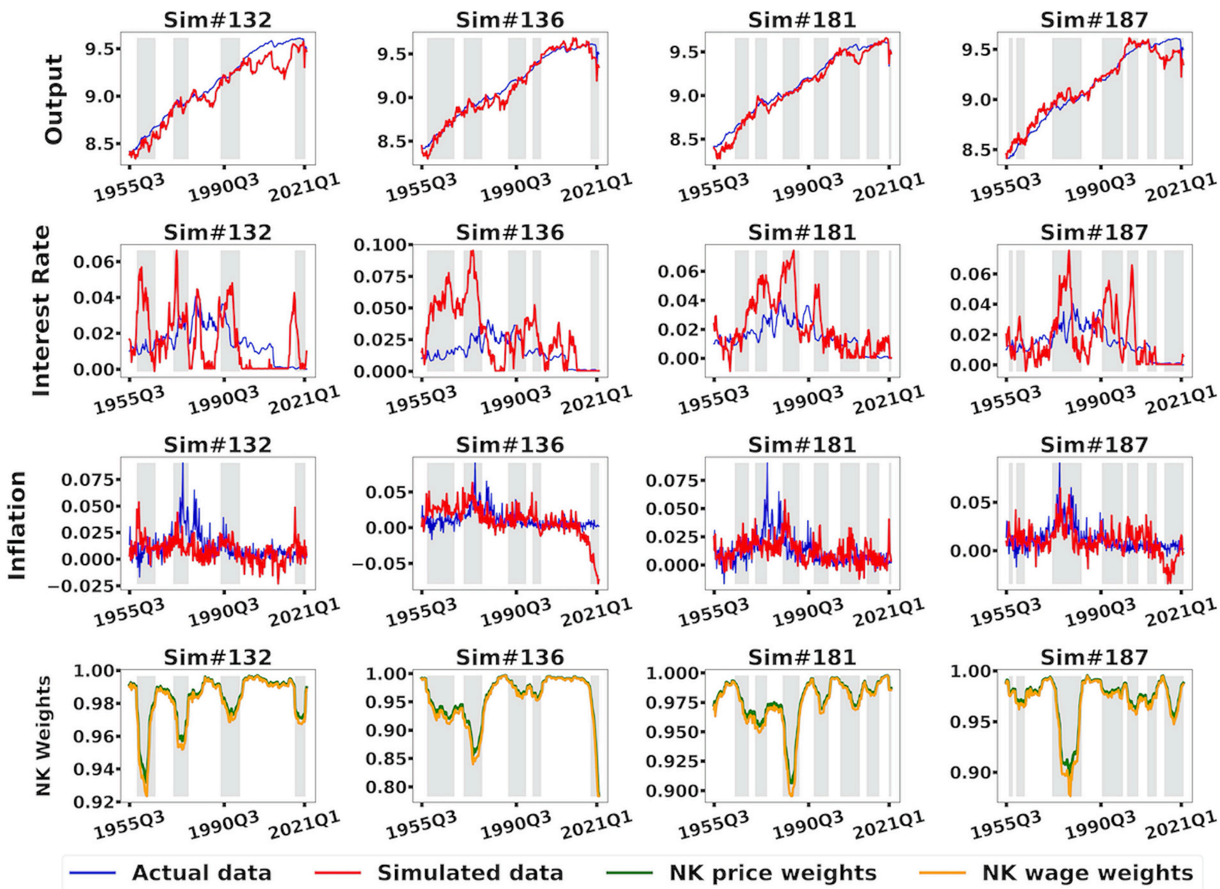


**Fig. 5.** A Selection of Simulations. Note: First, shaded areas show significant drops in the NK weights induced by notable inflation variance; in non-ZLB scenarios, interest rates respond to inflation fluctuations via the Taylor Rule. Second, our simulations for the 1955–1972 period do not include ZLB regime switches because the actual data during this time do not suffer from any ZLB issues. This explains the occasional negative interest rates in simulations prior to 1972, e.g. in Simulation#181.

**Table 3**
Auxiliary model parameter bounds.

| | Actual | 2.5th Percentile | 97.5th Percentile | In/Out |
|---|---|---|---|---|
| $\theta_{yy}$ | 0.9817 | 0.7663 | 0.9493 | Out |
| $\theta_{y\pi}$ | −0.0712 | −0.2964 | 0.4465 | In |
| $\theta_{yr}$ | 0.1644 | −0.5485 | 0.1798 | In |
| $\theta_{\pi y}$ | −0.0019 | −0.0149 | 0.0482 | In |
| $\theta_{\pi\pi}$ | 0.3572 | 0.0815 | 0.8136 | In |
| $\theta_{\pi r}$ | 0.1672 | −0.2273 | 0.2336 | In |
| $\theta_{ry}$ | 0.0030 | −0.0107 | 0.0495 | In |
| $\theta_{r\pi}$ | 0.0008 | −0.1596 | 0.0390 | In |
| $\theta_{rr}$ | 0.8936 | 0.8314 | 0.9999 | In |
| var($\epsilon^y$) | 0.000409 | 0.000578 | 0.001037 | Out |
| var($\epsilon^\pi$) | 0.000093 | 0.000061 | 0.000177 | In |
| var($\epsilon^r$) | 4.40e-06 | 8.39e-06 | 0.000092 | Out |

weights in these simulations, which change endogenously with inflation.

Table 3 shows the auxiliary model estimates on the actual data and the 95% confidence bounds from the simulations. We found that only one of the nine parameters lies outside the bounds, i.e., the model under-predicts the response of output to lagged output by a small margin. The data for interest rate variance and output variance are slightly below the model's 95% confidence bounds. However, the model fits overall, as indicated by the P-value of 0.087.

Fig. 6 shows the IRFs to a positive Taylor Rule (contractionary monetary policy) shock, which represents a pure demand shock. To analyse the effects of this shock, we examine two extreme cases: an entirely NK model and an entirely FP model. In the NK model, the NK weights are set to one, reflecting maximum price and wage rigidity with corresponding Calvo parameters. In contrast, the FP model sets the NK weights to zero, representing a scenario of complete price and wage flexibility. By comparing the NK and FP models, we observe how output and inflation respond differently depending on the degree of price and wage flexibility. Furthermore, since the estimated NK weights are state-dependent and vary across periods, these two extremes are particularly useful because they establish the boundaries for the potential range of responses. This, in turn, enables us to infer the effects of varying degrees of price and wage flexibility.

As illustrated in Fig. 6, the output response is more pronounced, but the inflation response is weaker under the NK model than in the FP model. The explanation for this difference is that under the NK model, a pure demand shock affects output directly; however, due to price rigidity, inflation does not respond much in the short run and only responds substantially to the resulting output gaps in the medium run. In the FP model (with flexible prices), the shock disturbs prices as they vary with changes in marginal costs and the output gap; however, the impact of the shock on output is limited as inflation responds quickly to stabilise output. Thus, in response to the demand disturbance, the NK model destabilises output but stabilises inflation through the Calvo framework, while the FP model stabilises output via flexible price adjustments. Overall, the FP model implies a rapid price response and a smaller real effect of monetary shocks than the NK model; output, consumption and labour exhibit smaller and less persistent responses, as shown in the figure.

Regarding the responses of open economy variables to a positive Taylor Rule shock, the interest rate under the NK model tends to remain at a higher level for a longer period to guide the economy towards the desired targets. This prolonged higher interest rate increases the real interest rate, which in turn has a pronounced and lasting impact on the real exchange rate, leading to more significant and prolonged effects on exports and imports in the NK model compared to the FP model.

The sign of the impulse response is fully consistent under both NK and NC models. A rise in the nominal interest rate hits consumption, investment, output, labour hours, real consumer wages and inflation negatively. In the financial sector, the shock decreases firms' net worth, which raises the external finance premium and further reduces investment. The decline in net worth leads to an increase in distressed borrowing, thereby resulting in a rise in M0. In the foreign sector, deflation and higher nominal interest rates (implying higher real interest rates) decrease the real exchange rate. Thus, the appreciation of sterling induces imports and lowers exports as domestic prices are relatively higher than foreign prices. The net foreign bond position decreases as net exports decrease.

The behaviour generated by our state-dependent model is in line with findings from micro-level studies. Specifically, it indicates that prices change more frequently during periods of high inflation. Thus, high inflation periods are closer to the scenario described in the FP model, i.e., prices respond to shocks more quickly and exhibit less persistence. Moreover, the real effect of monetary shocks is smaller.

Additionally, we employ variance decomposition to analyse the factors driving business cycles (see Tables 4 and 5).[9] Our findings indicate that, in the long run, productivity shocks are the dominant drivers of economic fluctuations, while monetary policy shocks including those from the Taylor Rule and QE - have smaller impacts, with QE contributing negligibly.

[9] Tables 4 and 5 show the analysis for the pre-1972 and post-1972 periods, respectively. To reiterate, for the pre-1972 period, the model's Taylor Rule equation has an exchange rate target included. The shock processes involved are detailed in Appendix B.

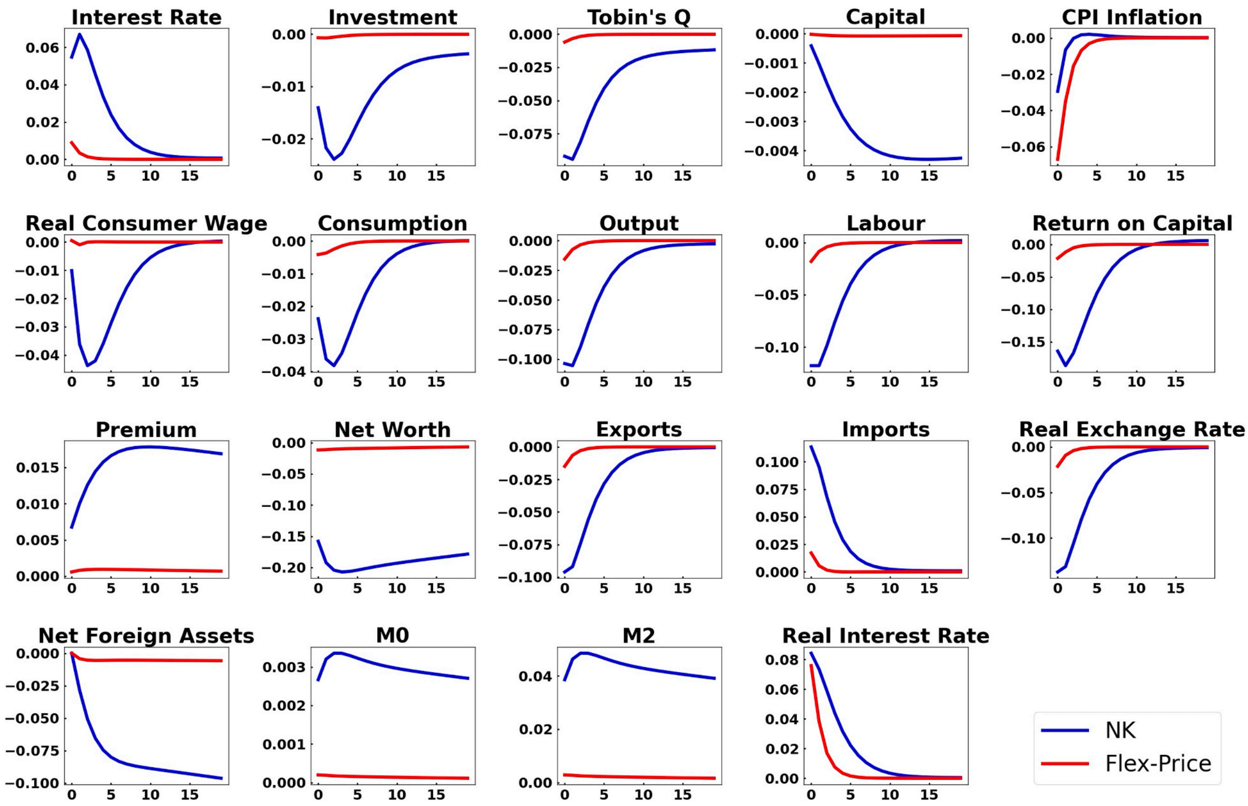


**Fig. 6.** IRFs to a Positive Taylor Rule Shock.

## 6. Policy implications

Our state-dependent model suggests that the volatility of inflation in the ZLB periods appears to be beyond the control of monetary policy despite the intervention of QE policy. As illustrated in Fig. 7, inflation shows greater volatility during ZLB episodes. The monetary policy's inability to stabilise inflation during these ZLB periods results in increased price duration volatility, which further exacerbates price volatility and hence inflation volatility. As a result, ZLB events in the state-dependent model trigger significant fluctuations in inflation. Bearing this in mind, as well as the fact that the UK's recovery from the Great Recession had been sluggish despite massive QE injections and the implementation of a ZLB interest rate, we examine an alternative policy framework, in which an interest rate policy targets nominal GDP (NGDP), complemented by a fiscal backstop designed to prevent the occurrence of the ZLB. We investigate whether this framework improves the UK's macroeconomic outcomes relative to the baseline framework, which combines the Taylor Rule with QE.

### *6.1. NGDP targeting Supplemented by ZLB-suppressing fiscal policy*

There is a growing interest in Market Monetarism, a macroeconomic theory advocating that central banks adopt an NGDP level target to stabilise nominal incomes, as suggested by Hendrickson (2012), Sumner (2012) and Woodford (2012), among others. It involves the use of a simple feedback rule whereby the central bank adjusts policy rates in response to deviations in NGDP from the level target; policy is history-dependent and must make up for any past overshoots or shortfalls in economic activity to bring NGDP back to the fixed path. Fackler and McMillin (2020) use a VAR model, and (Garín et al. 2016), Billi (2017, 2020), Benchimol and Fourçans (2019) and Beckworth and Hendrickson (2020) use DSGE models, suggesting that NGDP targeting could be a desirable alternative to the current monetary policy framework in the US. In the context of open economies, studies on this topic are limited. Bhandari and Frankel (2017) show that NGDP targeting outperforms inflation targeting in India. Benchimol (2024) finds that Taylor-type rules fit Israeli data better but suggests NGDP targeting may align more closely with central bank goals. Hatcher (2016) finds that NGDP targeting reduces tax volatility but increases average taxes compared to inflation targeting.

The NGDP targeting rule we examine is:

$$r_t = \rho_1 r_{t-1} + \rho_y (y_t + p_{d,t} - \overline{y}_t - \overline{p}_d) + \varepsilon_t \quad (30)$$

where $\overline{y}_t + \overline{p}_d$ represents the target for nominal GDP, $\overline{y}_t$ follows the real output generated by productivity, $\overline{p}_d$ as steady price level is

**Table 4**
Variance decompositions — Pre-1972 Model.

| Shock | Interest Rate | Investment | Inflation | Wage | Consumption | Output | Hours | Exports | Imports | Exchange rate |
|---|---|---|---|---|---|---|---|---|---|---|
| **Short-run (1 year)** | | | | | | | | | | |
| Government Spending | 1.8471 | 0.0527 | 2.0440 | 6.2473 | 0.2925 | 5.1139 | 1.6375 | 0.7566 | 3.9982 | 14.4187 |
| Consumer Preference | 0.0145 | 0.0056 | 0.0153 | 0.2374 | 14.2587 | 0.1134 | 0.0343 | 0.0025 | 1.7541 | 0.0482 |
| Investment | 0.5940 | 82.5751 | 1.0274 | 1.3144 | 1.1141 | 12.4884 | 3.3560 | 0.0613 | 0.4465 | 1.1687 |
| Taylor Rule | 54.5222 | 0.0035 | 14.5679 | 1.4366 | 7.9128 | 10.9079 | 3.3378 | 2.3340 | 5.5234 | 44.4819 |
| Productivity | 3.9240 | 16.6347 | 6.1271 | 30.5997 | 64.8986 | 6.7473 | 69.1611 | 1.1341 | 39.0954 | 2.4807 |
| Price Mark-up | 33.0149 | 0.0019 | 70.5412 | 9.0269 | 4.2590 | 6.2506 | 1.7905 | 1.3040 | 3.1919 | 24.8525 |
| Wage Mark-up | 0.4264 | 0.0928 | 0.6594 | 25.8835 | 0.6255 | 0.7210 | 0.3063 | 0.1386 | 0.3053 | 2.6411 |
| Labour Supply | 0.0744 | 0.0239 | 0.1147 | 2.8926 | 0.0954 | 0.1612 | 0.0628 | 0.0295 | 0.0727 | 0.5630 |
| Premium | 0.0003 | 0.0297 | 0.0001 | 0.0011 | 0.0011 | 0.0112 | 0.0027 | 0.0000 | 0.0003 | 0.0002 |
| Net Worth | 0.0829 | 0.5758 | 0.0601 | 0.3542 | 0.1553 | 1.6153 | 0.4716 | 0.0054 | 0.0803 | 0.1025 |
| M0 | 0.0000 | 0.0035 | 0.0000 | 0.0001 | 0.0001 | 0.0009 | 0.0002 | 0.0000 | 0.0000 | 0.0000 |
| Export | 4.3364 | 0.0004 | 3.8071 | 17.4066 | 5.0281 | 43.0840 | 15.7772 | 94.1280 | 4.1209 | 7.2230 |
| Import | 1.1630 | 0.0005 | 1.0357 | 4.5995 | 1.3588 | 12.7848 | 4.0621 | 0.1060 | 41.4110 | 2.0196 |
| **Long-run (5 years)** | | | | | | | | | | |
| Government Spending | 1.9235 | 0.1054 | 1.8881 | 1.9371 | 0.2571 | 4.3554 | 0.5900 | 0.8039 | 3.3287 | 13.9481 |
| Consumer Preference | 0.0153 | 0.0146 | 0.0161 | 0.0589 | 5.3582 | 0.1032 | 0.0127 | 0.0032 | 1.0679 | 0.0547 |
| Investment | 5.7817 | 26.5597 | 4.7961 | 3.2558 | 4.2096 | 5.4337 | 9.5888 | 0.2701 | 3.5395 | 4.6855 |
| Taylor Rule | 35.8297 | 0.0029 | 10.1758 | 0.6463 | 4.0892 | 10.8545 | 1.3975 | 1.8033 | 3.6204 | 31.2879 |
| Productivity | 30.1039 | 71.1890 | 29.3617 | 76.5496 | 80.5971 | 22.1032 | 79.1282 | 20.1838 | 55.0347 | 20.5744 |
| Price Mark-up | 19.6117 | 0.0013 | 47.9286 | 2.2982 | 1.8676 | 5.5981 | 0.6801 | 0.9196 | 1.9660 | 15.9561 |
| Wage Mark-up | 0.3812 | 0.2020 | 0.5231 | 6.3777 | 0.4414 | 0.9740 | 0.1409 | 0.1248 | 0.2334 | 2.1654 |
| Labour Supply | 0.1157 | 0.0856 | 0.1277 | 0.8570 | 0.1139 | 0.3240 | 0.0394 | 0.0383 | 0.0756 | 0.6643 |
| Premium | 0.0017 | 0.0572 | 0.0016 | 0.0009 | 0.0014 | 0.0685 | 0.0029 | 0.0001 | 0.0010 | 0.0013 |
| Net Worth | 0.1803 | 1.7106 | 0.1243 | 0.2595 | 0.1385 | 5.8787 | 0.3369 | 0.0133 | 0.1467 | 0.2302 |
| M0 | 0.0019 | 0.0579 | 0.0022 | 0.0004 | 0.0003 | 0.0393 | 0.0011 | 0.0001 | 0.0008 | 0.0020 |
| Export | 4.9545 | 0.0074 | 4.1030 | 6.3125 | 2.3507 | 32.7650 | 6.5337 | 75.7257 | 4.0128 | 8.4541 |
| Import | 1.0989 | 0.0063 | 0.9518 | 1.4460 | 0.5752 | 11.5025 | 1.5478 | 0.1139 | 26.9726 | 1.9762 |

Note: Values in the table are expressed in per cents.

**Table 5**
Variance decompositions — Post-1972 model.

| Shock | Interest Rate | Investment | Inflation | Wage | Consumption | Output | Hours | Exports | Imports | Exchange rate |
|---|---|---|---|---|---|---|---|---|---|---|
| **Short-run (1 year)** | | | | | | | | | | |
| Government Spending | 1.5721 | 0.0938 | 2.0675 | 2.2768 | 0.1343 | 2.2420 | 1.1728 | 0.5244 | 2.5622 | 12.9310 |
| Consumer Preference | 0.0481 | 0.0032 | 0.0578 | 0.3349 | 34.7796 | 0.2395 | 0.1166 | 0.0042 | 2.9547 | 0.1030 |
| Investment | 0.4632 | 37.6387 | 0.9285 | 0.4446 | 0.6537 | 6.0194 | 2.6073 | 0.0252 | 0.1815 | 0.6202 |
| Taylor Rule | 63.4654 | 0.0023 | 19.6530 | 0.7254 | 6.9309 | 7.8489 | 3.8709 | 1.4292 | 3.3509 | 35.2394 |
| Productivity | 5.6690 | 61.0130 | 9.5156 | 43.4846 | 38.2521 | 16.2945 | 57.4493 | 43.1622 | 37.2581 | 2.4392 |
| Price Mark-up | 23.4126 | 0.2149 | 61.7214 | 8.4583 | 8.2600 | 9.4030 | 4.2980 | 1.4376 | 3.3279 | 35.4481 |
| Wage Mark-up | 0.8395 | 0.5076 | 1.6485 | 26.9563 | 2.2499 | 1.9646 | 1.2157 | 0.2602 | 0.5153 | 6.4156 |
| Labour Supply | 0.5960 | 0.1144 | 1.0901 | 10.1241 | 0.7819 | 1.0542 | 0.6449 | 0.1694 | 0.4157 | 4.1763 |
| Premium | 0.0017 | 0.1149 | 0.0009 | 0.0032 | 0.0042 | 0.0393 | 0.0149 | 0.0000 | 0.0009 | 0.0010 |
| Net Worth | 0.0717 | 0.2911 | 0.0603 | 0.1329 | 0.1011 | 0.8636 | 0.4063 | 0.0024 | 0.0362 | 0.0603 |
| M0 | 0.0001 | 0.0059 | 0.0000 | 0.0002 | 0.0002 | 0.0019 | 0.0007 | 0.0000 | 0.0000 | 0.0001 |
| Export | 2.3092 | 0.0001 | 1.8600 | 4.2818 | 5.1835 | 35.3251 | 18.5753 | 52.9385 | 1.2563 | 1.4152 |
| Import | 1.5516 | 0.0001 | 1.3963 | 2.7769 | 2.6685 | 18.7039 | 9.6271 | 0.0467 | 48.1402 | 1.1506 |
| **Long-run (5 years)** | | | | | | | | | | |
| Government Spending | 1.0979 | 0.1602 | 1.2280 | 0.4181 | 0.1541 | 1.7352 | 0.3781 | 0.5770 | 1.5715 | 9.6216 |
| Consumer Preference | 0.0232 | 0.0059 | 0.0285 | 0.0498 | 7.7181 | 0.1781 | 0.0371 | 0.0038 | 1.3575 | 0.0633 |
| Investment | 10.3340 | 19.2371 | 9.8482 | 1.6289 | 0.4254 | 6.2685 | 5.1089 | 0.8598 | 3.1233 | 14.3377 |
| Taylor Rule | 27.6180 | 0.0018 | 8.7631 | 0.1988 | 2.1159 | 6.8214 | 1.4327 | 1.1763 | 1.6637 | 19.6141 |
| Productivity | 45.8053 | 78.1086 | 47.9000 | 87.9928 | 82.0422 | 23.2591 | 74.6539 | 13.8187 | 64.1677 | 25.4604 |
| Price Mark-up | 9.1860 | 0.1840 | 26.7676 | 1.4142 | 2.2393 | 7.5098 | 1.4457 | 1.0770 | 1.5367 | 17.9594 |
| Wage Mark-up | 0.7407 | 0.8573 | 1.0835 | 4.0338 | 1.0141 | 2.8436 | 0.4675 | 0.3359 | 0.4648 | 5.6014 |
| Labour Supply | 0.5850 | 0.3386 | 0.7389 | 1.8162 | 0.5496 | 1.7011 | 0.3381 | 0.2156 | 0.2895 | 3.5947 |
| Premium | 0.0120 | 0.2278 | 0.0126 | 0.0021 | 0.0041 | 0.2080 | 0.0197 | 0.0005 | 0.0038 | 0.0083 |
| Net Worth | 0.1033 | 0.8037 | 0.0795 | 0.0593 | 0.0533 | 2.7449 | 0.2566 | 0.0064 | 0.0501 | 0.1072 |
| M0 | 0.0017 | 0.0730 | 0.0023 | 0.0002 | 0.0003 | 0.0659 | 0.0017 | 0.0001 | 0.0004 | 0.0012 |
| Export | 3.5720 | 0.0011 | 2.7255 | 1.8590 | 2.9830 | 31.6754 | 12.5498 | 81.8767 | 1.8274 | 2.7627 |
| Import | 0.9208 | 0.0009 | 0.8222 | 0.5269 | 0.7007 | 14.9890 | 3.3103 | 0.0520 | 23.9437 | 0.8679 |

Note: Values in the table are expressed in per cents.

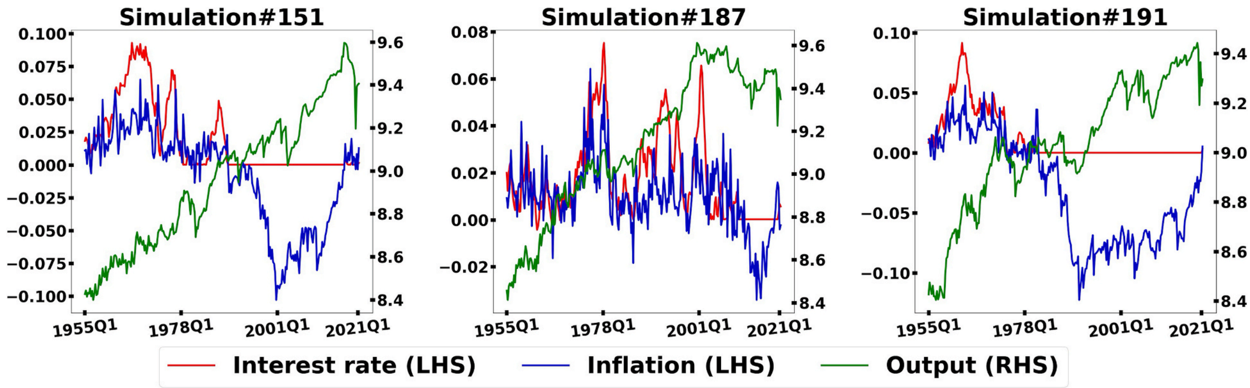


**Fig. 7.** A Selection of Simulations - Inflation Fluctuations in ZLB.

assumed to be constant and normalised to zero, and $\rho_y$ is the partial elasticity of interest rate with respect to the nominal GDP deviation. $y_t + p_{d,t} - \bar{y}_t - \bar{p}_d$ is the deviation of NGDP from the target, a combination of a stronger response to output gap $(y_t - \bar{y}_t)$ plus domestic price level targeting $\left(p_{d,t} - \bar{p}_d\right)$ in place of an inflation target. The former implies more output stability. The latter produces a more persistent response on interest rates to inflation shocks as it gets back to the same level, i.e., it produces a forward guidance effect and is more strongly in stabilising inflation. When faced with demand shocks, both price and output move in the same direction, hence requiring the same interest rate response. Compared to inflation targeting, NGDP targeting could stabilise both inflation and output more strongly due to the persistent/forward guidance effect. However, a dilemma arises in the event of supply shocks: price and output move in opposite directions. NGDP targeting could stabilise inflation but may worsen output. Because the NGDP target creates persistence in the interest rate response with a forward guidance effect, this is a powerful stabiliser of current inflation. It could worsen output response by stabilising current inflation more. We empirically check this later.

Additionally, there is an increasing recognition that monetary policy alone cannot bring the economy out of the liquidity trap and achieve price and economic stability; monetary-fiscal coordination is needed more than ever; see Blanchard et al. (2010), Bhattarai and Egorov (2016), Portes and Wren-Lewis (2015), Praščević and Ješić (2019), Nasir (2021) and Ascari et al. (2023). As highlighted earlier, our analysis of NGDP targeting is accompanied by a ZLB-suppressing fiscal rule to eliminate the greater inflation volatility during ZLB episodes induced by the interaction of state-dependence and the ZLB. Once the monetary policy is constrained by the ZLB, the fiscal policy serves as a backstop against the ZLB by preventing ZLB episodes from arising, thereby keeping the monetary policy of NGDP targeting effective. This enhances the stabilising role of monetary policy. Our baseline fiscal policy regime and fiscal ZLB-suppression regime are presented below:

Baseline regime:

$$\varepsilon_t^g = \rho_g \varepsilon_{t-1}^g + \sigma_{ga}\eta_t^\alpha + \eta_t^g, \eta_t^g \sim N\left(0, \sigma_g^2\right) \eta_t^a \sim N\left(0, \sigma_a^2\right) \tag{31}$$

Where $\varepsilon_t^g$ is the government spending shock, $\eta_t^g$ and $\eta_t^\alpha$ are the government spending and the productivity innovations, respectively.

Fiscal ZLB-suppression regime:

$$\varepsilon_t^g = \rho_g \varepsilon_{t-1}^g + \sigma_{ga}\eta_t^\alpha + \eta_t^g + \boldsymbol{f_t}, \eta_t^g \sim N\left(0, \sigma_g^2\right) \eta_t^a \sim N\left(0, \sigma_a^2\right) \tag{32}$$

Where $f_t$ is the fiscal shock that pushes interest rate away from the ZLB.

### 6.2. Empirical investigation results

We combine the NGDP targeting rule with the fiscal ZLB-suppression policy to investigate whether shifting to this alternative policy framework would improve macroeconomic stability relative to the baseline framework of the Taylor Rule with QE. In the comparison, we consider the following criteria. First, the frequency of crises under the two policy frameworks; this measures the effectiveness of policies in preventing crises, viewed as severe recessions. Second, the variance of inflation. Third, the variance of output around a measure of trend output.[10] Fourth, the welfare cost, which is calculated as a weighted sum of the variances of inflation and output. We use simulation analysis to examine all these criteria to see whether the alternative policy framework produces attractive results.

In our estimated model, we replace the baseline policy framework with the NGDP targeting accompanied by the fiscal backstop framework and find that the rule of the following form can improve the performance of monetary policy:

[10] We create our trend output measure by adding the balanced growth path found in the data to the simulated productivity shocks.

**Table 6**
Stability and crises comparison.

| | Taylor Rule + QE | NGDP targeting + fiscal ZLB-suppression |
|---|---|---|
| Shallow crises[a] | 39.65 | 37.86 |
| Deep crises[a] | 30.94 | 24.62 |
| Var(Output) | 0.00107 | 0.00088 |
| Var(Inflation) | 0.0016 | 1.04e-04 |
| Welfare[b] | 0.00134 | 0.00049 |
| Var(Interest rate) | 0.00411 | 0.01059 |
| Av. NK weight wage | 0.9085 | 0.9831 |
| Av. NK weight price | 0.9126 | 0.9874 |

[a]Expected number of crises per 1000 years. Shallow and deep crises are defined as small and large declines in output, respectively, where output does not return to its previous peak within five years.
[b]The measurement of welfare costs is based on a weighted resource cost due to price variability and output variability: $welfare = 0.5 * var(\pi) + 0.5 * var(y)$.

$$r_t = 0.30r_{t-1} + 1.50\left(y_t + p_{d,t} - \overline{y}_t - \overline{p}_d\right) + \varepsilon_t \tag{33}$$

Table 6 summarises the average bootstrap simulation results for the two policy frameworks. Regarding the ability of each policy framework to reduce the number of crises, we examine the expected number of shallow and deep crises per 1000 years; shallow (or deep) crises are defined as small (or large) declines in output, where output does not return to its previous peak within five years. The simulations show that the 'NGDP targeting with fiscal ZLB-suppression' framework provides a modest improvement in reducing the number of shallow crises, and a significant enhancement in reducing the number of deep crises.

From a stabilisation perspective, our simulations show that the alternative framework yields a lower output variance and a significantly lower inflation variance than the baseline framework; there is a modest accompanying rise in the interest rate variance, as ZLB episodes of zero movement are eliminated while rates move strongly to implement the more demanding NGDP target. With respect to welfare costs, the alternative framework is associated with a significantly smaller welfare loss than the baseline framework. Fig. 8 presents some examples of the bootstrap simulations under the two frameworks. As observed, the alternative framework (in red) effectively prevents the occurrence of ZLB. Compared to the baseline framework (in blue), it stabilises inflation considerably and somewhat smooths output, although it appears to increase interest rates.

Regarding the price duration, the alternative framework generates a higher average NK price weight of 0.9874 compared to the baseline framework's 0.9126, due to the fact that the lower the inflation volatility, the higher the NK weight of prices. As shown in Fig. 8, the alternative framework heavily stabilises inflation and therefore largely eliminates the destabilising behaviour in price/wage durations, leading to long price/wage durations.

We further compare the responses of both policy frameworks to demand and supply shocks separately. As Table 7 illustrates, the alternative framework provides stronger stability to both inflation and output in scenarios of demand shocks. Conversely, Table 8 shows that while the alternative framework stabilises inflation, it worsens the output response when the economy is subject to supply shocks. Under supply shocks, price and output move in contrary directions, requiring different interest rate responses. The alternative framework is a powerful stabiliser of current inflation, consequently worsening the output response by stabilising current inflation more. Given that output fluctuations are primarily driven by demand shocks (as shown in the variance decomposition analysis; see Tables 4 and 5), the alternative framework generates lower output and inflation variances overall.

Our findings of lower inflation and output variances in the alternative framework generally support the results from the literature employing DSGE models with fixed price/wage contracts, such as those by Benchimol and Fourçans (2019) and Beckworth and Hendrickson (2020).

## 7. Conclusion

Despite the considerable micro-level evidence of state-dependent price/wage duration, there is a noticeable scarcity of literature examining it at the macro level. Among the few macro-level studies conducted, all have been focused on closed economy DSGE models in the US context. This paper fills this gap by studying how macroeconomic behaviour is affected by state-dependence in an open economy context. We develop a state-dependent DSGE model for the UK economy to investigate whether there is macro-level evidence to corroborate the micro-level findings of state-dependence. Our Indirect Inference estimation and test results indicate that the state-dependent model fits the dynamic behaviour of the key variables over the sample period 1955–2021. Our state-dependent model produces behaviour that is consistent with the literature, i.e. in periods of high inflation, prices respond to shocks quickly and with low persistence, leading to a smaller real impact of monetary shocks. Furthermore, the price/wage contract durations fluctuate with the state of the economy (inflation) throughout the whole sample.

In the state-dependent scenario, apart from directly responding to shocks, monetary policy also determines the price/wage stickiness of the economy, which in turn indirectly affects the response to these shocks. As a result, under the interaction of state-dependence and ZLB, monetary-fiscal coordination is needed to stabilise the economy, as monetary policy alone cannot achieve economic stability during ZLB scenarios. By examining a coordinated monetary-fiscal policy framework, i.e., an interest rate policy that targets NGDP complemented by a fiscal ZLB-suppression rule, we find that this alternative policy framework outperforms the

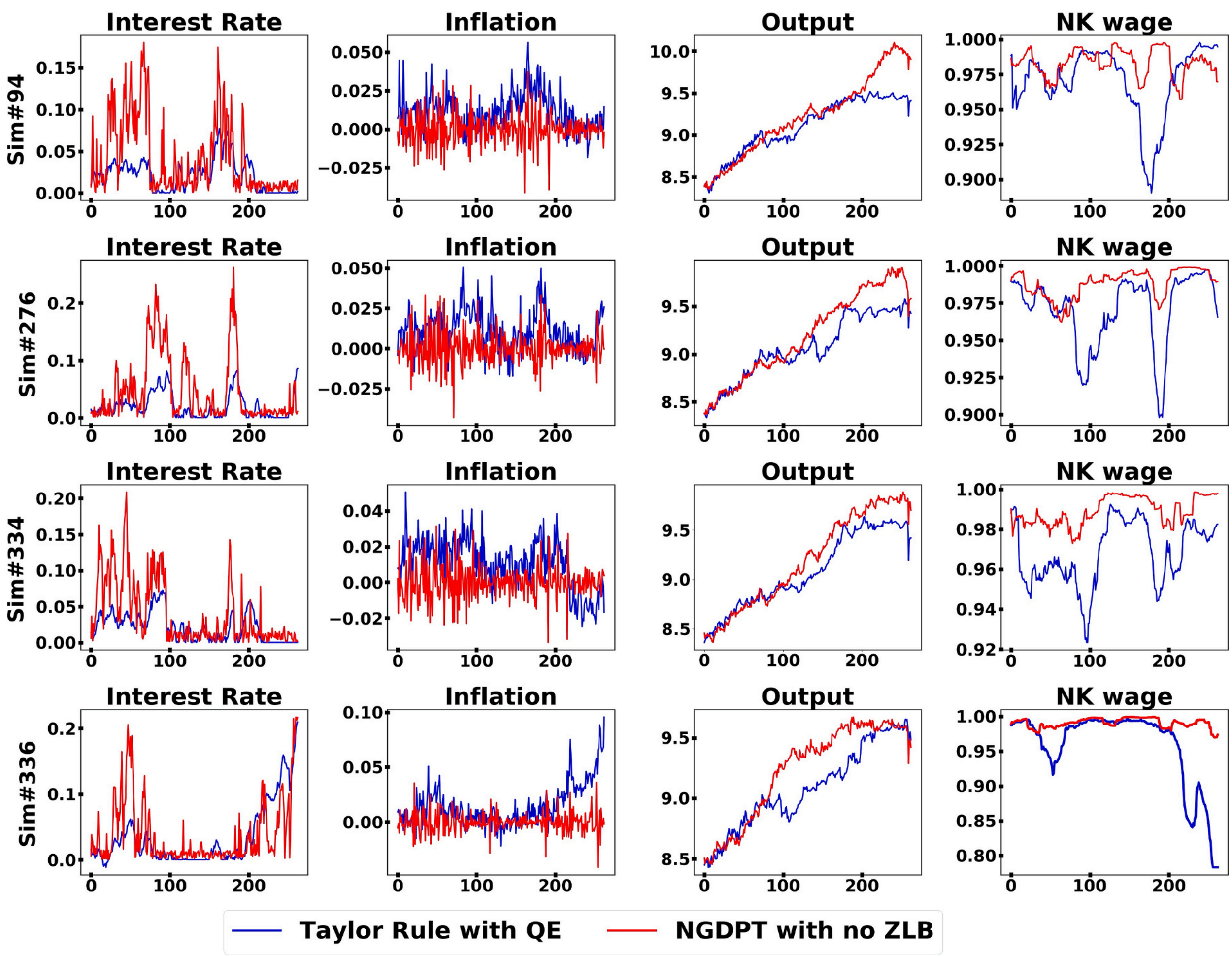


**Fig. 8.** Simulation Comparison.

**Table 7**
Stability comparison in response to demand shocks.

| | Taylor Rule + QE | NGDP targeting + fiscal ZLB-suppression |
|---|---|---|
| Var(Output) | 1.77e-04 | 1.02e-04 |
| Var(Inflation) | 9.00e-06 | 8.18e-06 |
| Welfare[b] | 9.30e-05 | 5.51e-05 |

[a] The results were computed through bootstrapping the model and demand shocks (Taylor Rule and government spending shocks).
[b] Welfare = 0.5 * var($\pi$) + 0.5 * var($y$).

**Table 8**
Stability comparison in response to supply shocks.

| | Taylor Rule + QE | NGDP targeting + fiscal ZLB-suppression |
|---|---|---|
| Var(Output) | 3.60e-05 | 4.13e-05 |
| Var(Inflation) | 0.0013 | 7.22e-04 |
| Welfare[b] | 6.68e-04 | 3.82e-04 |

[a] The results were computed through bootstrapping the model and supply shocks (productivity and labour supply shocks).
[b] Welfare = 0.5 * var($\pi$) + 0.5 * var(y).

baseline framework of the Taylor Rule with QE in terms of its ability to avoid crises and decrease welfare costs; the regime implies a higher interest rate variance as the ZLB is avoided and rates respond more strongly to the demanding NGDP target. Notably, this alternative framework provides a stronger stabilisation of inflation and output under demand shocks than the baseline framework; due to its power in stabilising prices, it worsens the output response to supply shocks by holding down the price response. But overall it enhances the stability of both output and inflation because demand shocks predominate. Additionally, the alternative framework significantly stabilises inflation, which in turn stabilises price/wage durations, resulting in long price/wage durations.

Practical questions remain as to whether this alternative regime can be implemented politically. The NGDP target implies keeping interest rates away from normal rates for long periods after inflation has returned to normal; this is vulnerable to time-inconsistency, because of the temptation to bring rates back down. The fiscal backstop requires sharp changes in government borrowing which may be hard to implement in the face of market opinion. These questions of practical implementation no doubt account for the lack of examples of these policies around the world. What our model reveals however is that they have potential benefits if such practical obstacles can be overcome.

## CRediT authorship contribution statement

**Haixia Chen:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Vo Phuong Mai Le:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **David Meenagh:** Writing – review & editing, Validation, Supervision, Software, Conceptualization. **Patrick Minford:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Log-linearised model List

Consumption Euler Equation

$$c_t = \frac{\frac{h}{\gamma}}{1+\frac{h}{\gamma}} c_{t-1} + \frac{1}{1+\frac{h}{\gamma}} E_t\, c_{t+1} + \frac{(\sigma_c - 1)\frac{W_* L_*}{C_*}}{\left(1+\frac{h}{\gamma}\right)\sigma_c}(l_t - E_t\, l_{t+1}) - \frac{1-\frac{h}{\gamma}}{\left(1+\frac{h}{\gamma}\right)\sigma_c}\left(r_t - E_t\, \pi^{cpi}_{t+1}\right) + \varepsilon^b_t \tag{A.1}$$

Investment Euler Equation

$$i_t = \frac{1}{1+\beta\gamma^{(1-\sigma_c)}} i_{t-1} + \frac{\beta\gamma^{1-\sigma_c}}{1+\beta\gamma^{1-\sigma_c}} E_t i_{t+1} + \frac{1}{(1+\beta\gamma^{(1-\sigma_c)})\gamma^2\varphi} qq_t + \varepsilon^i_t \tag{A.2}$$

Production Function

$$y_t = \phi\left[\alpha k^s_t + (1-\alpha) l_t + \varepsilon^a_t\right] \tag{A.3}$$

Capital Accumulation Equation

$$k_t = \left(\frac{1-\delta}{\gamma}\right) k_{t-1} + \left(1 - \frac{1-\delta}{\gamma}\right) i_t + \left(1 - \frac{1-\delta}{\gamma}\right)\left((1+\beta\gamma^{(1-\sigma_c)})\gamma^2\varphi\right)\varepsilon^i_t \tag{A.4}$$

Current Capital Service

$$k^s_t = k_{t-1} + z_t \tag{A.5}$$

Capital Utilisation

$$z_t = \frac{1-\psi}{\psi} rk_t \tag{A.6}$$

Capital Arbitrage (Tobin' Q) Equation

$$qq_t = \frac{1-\delta}{1-\delta+R^K_*} E_t qq_{t+1} + \frac{R^K_*}{1-\delta+R^K_*} E_t rk_{t+1} - E_t cy_{t+1} \tag{A.7}$$

Demand for Labour

$$l_t = -w_t^h + \left(1 + \frac{1-\psi}{\psi}\right) rk_t + k_{t-1} \tag{A.8}$$

External Finance Premium

$$\text{prem}_t = E_t cy_{t+1} - \left(r_t - E_t \pi_{t+1}^{cpi}\right) = \chi(qq_t + k_t - n_t) - \vartheta m_t^0 + \varepsilon_t^{\text{prem}} \tag{A.9}$$

Net Worth Evolution

$$n_t = \frac{K}{N}(cy_t - E_{t-1} cy_t) + E_{t-1} cy_t + \theta n_{t-1} + \varepsilon_t^{nw} \tag{A.10}$$

Consumption of Entrepreneurs

$$c_t^e = n_t \tag{A.11}$$

Hybrid Domestic Price Setting (Weighted Home Inflation)

$$\begin{aligned} \left(\pi_t^h\right)^{NK} : \pi_t^h = {} & \frac{\beta\gamma^{1-\sigma_c}}{1+\beta\gamma^{(1-\sigma_c)} \iota_p} E_t \pi_{t+1}^h + \frac{\iota_p}{1+\beta\gamma^{(1-\sigma_c)} \iota_p} \pi_{t-1}^h - \frac{1}{1+\beta\gamma^{(1-\sigma_c)} \iota_p} \\ & \left(\frac{\left(1-\beta\gamma^{(1-\sigma_c)}\xi_p\right)\left(1-\xi_p\right)}{\xi_p\left(1+(\phi_p-1)\epsilon_p\right)}\right)\left(\alpha rk_t + (1-\alpha) w_t^h - \varepsilon_t^a\right) + \varepsilon_t^p \end{aligned} \tag{A.12}$$

NC Marginal Product of Labour

$$\left(\pi_t^h\right)^{NC} : rk_t = \frac{1}{\alpha}\left[-(1-\alpha) w_t^h + \varepsilon_t^a\right] \tag{A.13}$$

$$\left(\pi_t^h\right)^{hybrid} = \omega^p \left(\pi_t^h\right)^{NK} + (1-\omega^p)\left(\pi_t^h\right)^{NC} \tag{A.14}$$

Hybrid Real Consumer Wage Setting

$$\begin{aligned} \left(w_t^c\right)^{NK} : w_t^c = {} & \frac{\beta\gamma^{1-\sigma_c}}{1+\beta\gamma^{1-\sigma_c}} E_t w_{t+1}^c + \frac{1}{1+\beta\gamma^{1-\sigma_c}} w_{t-1}^c + \frac{\beta\gamma^{1-\sigma_c}}{1+\beta\gamma^{1-\sigma_c}} E_t \pi_{t+1}^{cpi} \\ & - \frac{1+\left(\beta\gamma^{(1-\sigma_c)}\right)\iota_w}{1+\beta\gamma^{1-\sigma_c}} \pi_t^{cpi} + \frac{\iota_w}{1+\beta\gamma^{1-\sigma_c}} \pi_{t-1}^{cpi} - \frac{1}{1+\beta\gamma^{1-\sigma_c}} \left(\frac{\left(1+\beta\gamma^{(1-\sigma_c)}\xi_w\right)(1-\xi_w)}{\xi_w(1+(\phi_w-1)\epsilon_w)}\right) \\ & \left(w_t^c - \sigma_l l_t - \left(\frac{1}{1-\frac{h}{\gamma}}\right)\left(c_t - \frac{h}{\gamma} c_{t-1}\right)\right) + \varepsilon_t^{w_{NK}} \end{aligned} \tag{A.15}$$

NC Labour Supply

$$\left(w_t^c\right)^{NC} : w_t^c = \sigma_l l_t + \left(\frac{1}{1-\frac{h}{\gamma}}\right)\left(c_t - \frac{h}{\gamma} c_{t-1}\right) - \left(\pi_t^{cpi} - E_{t-1}\pi_t^{cpi}\right) + \varepsilon_t^{w_{NC}} \tag{A.16}$$

$$w_t^{\text{hybrid}} = \omega^w \left(w_t^c\right)^{NK} + (1-\omega^w)\left(w_t^c\right)^{NC} \tag{A.17}$$

Monetary Policy for Normal Regime (Non-crisis)

$$\text{For } r_t > 0.025\% \begin{cases} r: & r_t = \rho r_{t-1} + (1-\rho)\left(r_p \pi_t^{cpi} + r_y y_t\right) + r_{\Delta y}(y_t - y_{t-1}) + \varepsilon_t^r \\ M0: & m_t^0 = m_{t-1}^0 + \vartheta_1\left(m_t^2 - m_{t-1}^2\right) + \varepsilon_t^{m0,nocrisis} \\ M2: & m_t^2 = (1+\nu-\mu) k_t + \mu m_t^0 - \nu n_t, \nu = \dfrac{N}{M2}, \mu = \dfrac{M0}{M2} \end{cases} \tag{A.18}$$

Monetary Policy for Crisis Regime

$$\text{For } r_t \le 0.025\% \begin{cases} M0: & m_t^0 = m_{t-1}^0 + \vartheta_2(prem_t - prem^*) + \varepsilon_t^{m0,crisis} \\ r: & r = 0.025\% \end{cases} \tag{A.19}$$

Real Uncovered Interest Rate Parity

$$q_t = E_t q_{t+1} + \left(r_t^f - E_t \pi_{t+1}^f\right) - \left(r_t - E_t \pi_{t+1}^{cpi}\right) \tag{A.20}$$

Import Demand

$$im_t = \ln\omega + c_t - \sigma q_t + \varepsilon_t^{im} \tag{A.21}$$

Export Demand

$$ex_t = \ln\omega^f + c_t^f + \sigma^f q_t + \varepsilon_t^{ex} \tag{A.22}$$

Net Foreign Assets Evolution

$$b_t^f = \left(1 + r_{t-1}^f\right) b_{t-1}^f + \frac{EX}{Y}(ex_{t-1} - q_{t-1}) - \frac{IM}{Y} im_{t-1} \tag{A.23}$$

CPI Inflation

$$\pi_t^{cpi} = \pi_t^h + \frac{\omega}{1-\omega}\Delta q_t \tag{A.24}$$

The Wedge Between the Real Consumer Wage and Real Producer Wage

$$w_t^h = w_t^c + \frac{\omega}{1-\omega} q_t \tag{A.25}$$

Aggregate Resource Constraint

$$y_t = \frac{C}{Y}c_t + \frac{I}{Y}i_t + R_*^K k_y \frac{1-\psi}{\psi} rk_t + \frac{C^e}{Y}c_t^e + \frac{EX}{Y}ex_t - \frac{IM}{Y}im_t + \varepsilon_t^g \tag{A.26}$$

**Exogenous Processes**

Government spending shock:.$\varepsilon_t^g = \rho_g \varepsilon_{t-1}^g + \sigma_{ga}\eta_t^a + \eta_t^g$
Preference shock:.$\varepsilon_t^b = \rho_b \varepsilon_{t-1}^b + \eta_t^b$
Productivity shock:.$(\varepsilon_t^a - \varepsilon_{t-1}^a) = \rho_a(\varepsilon_t^a - \varepsilon_{t-1}^a) + \eta_t^a$
Investment-specific shock:.$\varepsilon_t^i = \rho_i \varepsilon_{t-1}^i + \eta_t^i$
Taylor Rule shock:.$\varepsilon_t^r = \rho_r \varepsilon_{t-1}^r + \eta_t^r$
Price mark-up shock:.$\varepsilon_t^p = \rho_p \varepsilon_{t-1}^p + \eta_t^p$
NK wage mark-up shock:.$\varepsilon_t^{wNK} = \rho_w^{nk} \varepsilon_{t-1}^{wNK} + \eta_t^{wNK}$
NC wage mark-up (labour supply) shock:.$\varepsilon_t^{w_{NC}} = \rho_w^{nc} \varepsilon_{t-1}^{w_{NC}} + \eta_t^{wNC}$
External finance premium shock:.$\varepsilon_t^{prem} = \rho_{pr} \varepsilon_{t-1}^{prem} + \eta_t^{prem}$
Net worth shock:.$\varepsilon_t^{nw} = \rho_{nw} \varepsilon_{t-1}^{nw} + \eta_t^{nw}$
Export demand shock:.$\varepsilon_t^{ex} = \rho_{ex} \varepsilon_{t-1}^{ex} + \eta_t^{ex}$
Import demand shock:.$\varepsilon_t^{im} = \rho_{im} \varepsilon_{t-1}^{im} + \eta_t^{im}$
Exogenous foreign consumption process:.$c_t^f = \rho_c^f c_{t-1}^f + \eta_t^{cf}$
Exogenous foreign interest rate process:.$r_t^f = \rho_r^f r_{t-1}^f + \eta_t^{rf}$
Money supply shock (crisis shock): $\varepsilon_t^{m0,\ \text{crisis}} = \rho_{m0,\ \text{crisis}} \varepsilon_{t-1}^{m0,\ \text{crisis}} + \eta_t^{m0,\ \text{crisis}}$
Money supply shock (non-crisis shock): $\varepsilon_t^{m0,\ \text{nocrisis}} = \rho_{m0,\ \text{nocrisis}} \varepsilon_{t-1}^{m0,\ \text{nocrisis}} + \eta_t^{m0,\text{nocrisis}}$

## Appendix B. Shock and residual histories and fixed parameters

Fig. B1, Fig. B2, Table B1 and Table B2.

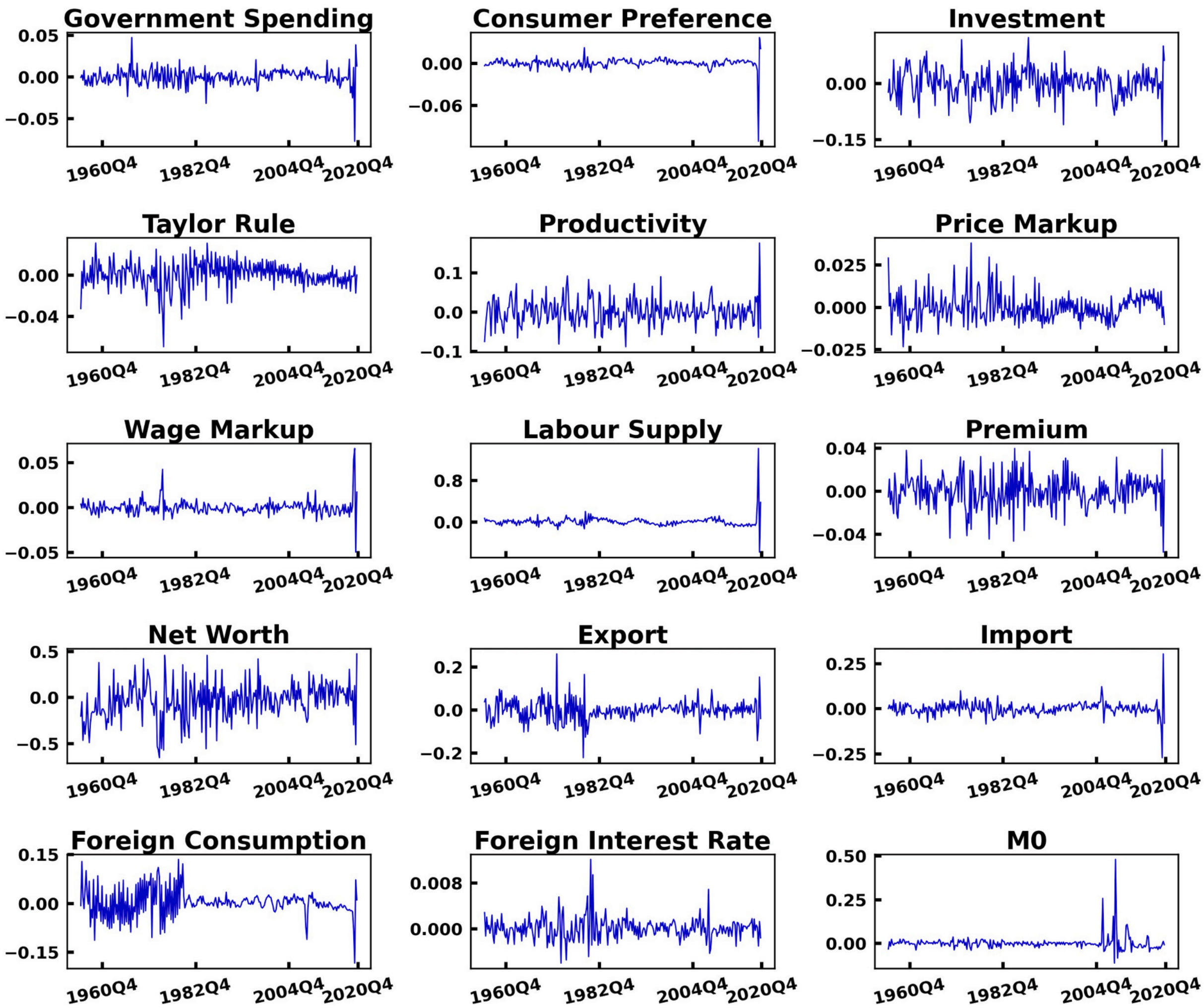


**Fig. B1.** Model Implied Shock Histories

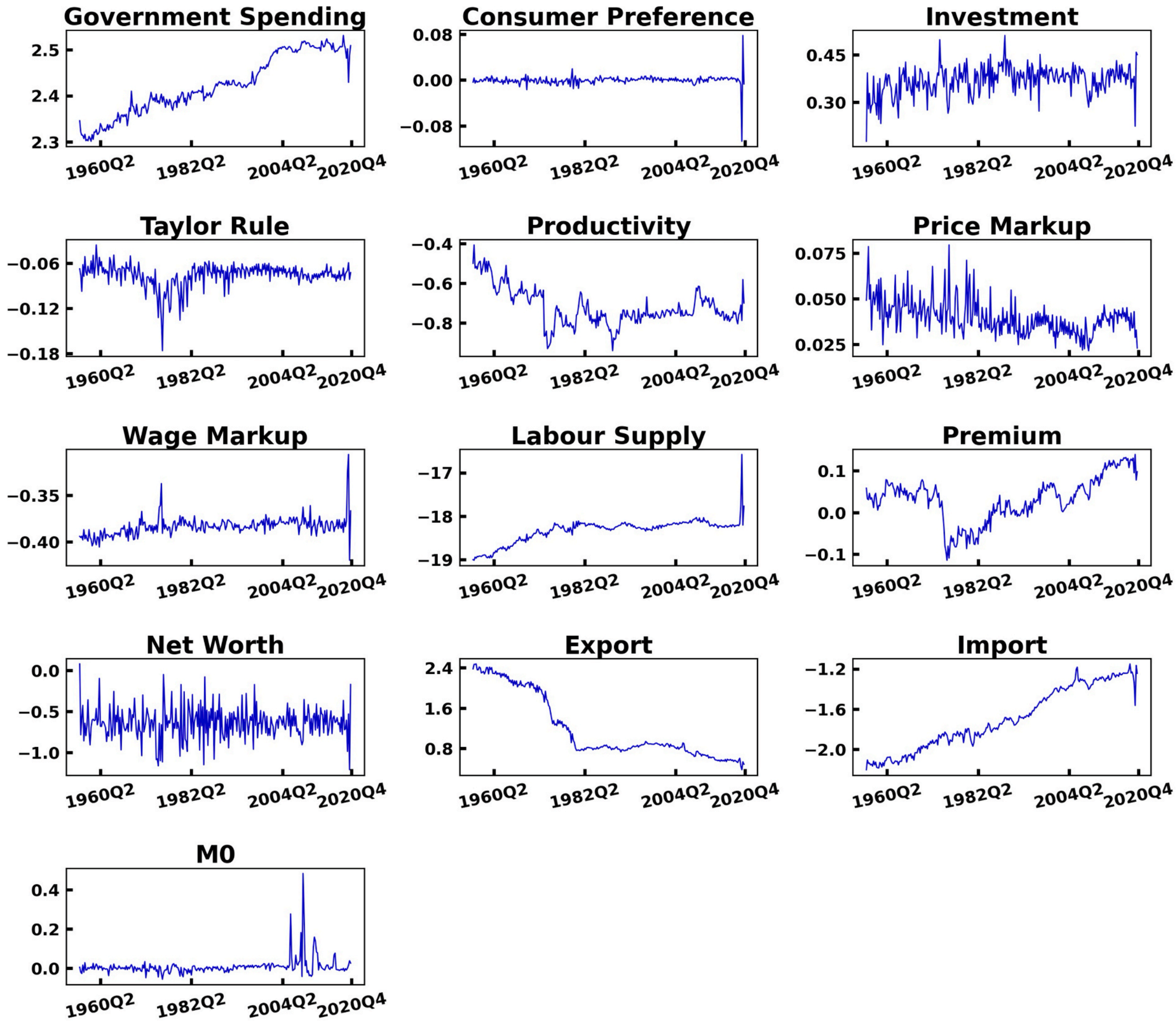


**Fig. B2.** Model Implied Residual Histories

**Table B1**
Stationarity of residuals and AR(1) coefficients.

| Shock | AR(1) Coefficient | ADF P-value[a] | KPSS Statistic[b] | Conclusion |
|---|---|---|---|---|
| Pre-1972 Period | | | | |
| Government | 0.3585 | 0.0000*** | 0.0854 | Stationary |
| Preference | −0.2783 | 0.0000*** | 0.1238 | Stationary |
| Investment | −0.1132 | 0.0308** | 0.6316++ | Trend Stationary |
| Taylor Rule | 0.0307 | 0.0014*** | 0.6141++ | Trend Stationary |
| Productivity | −0.3941 | 0.1612 | 0.1464++ | Non-stationary |
| Price mark-up | −0.0192 | 0.0000*** | 0.3944+ | Trend Stationary |
| Wage mark-up | 0.0686 | 0.0350** | 0.0851 | Stationary |
| Labour supply | 0.4913 | 0.2965 | 0.1038 | Trend Stationary |
| Premium | 0.6076 | 0.0511* | 0.2093 | Stationary |
| Net worth | −0.0412 | 0.0001*** | 0.1274 | Stationary |
| M0(crisis) | −0.2462 | 0.0001*** | 0.0989 | Stationary |
| M0(noncrisis) | −0.2326 | 0.0002*** | 0.1514 | Stationary |
| Export | 0.1119 | 0.0674* | 0.0873 | Stationary |
| Import | 0.5567 | 0.2924 | 0.3056+++ | Trend Stationary[c] |
| Post-1972 Period | | | | |
| Government | 0.8041 | 0.1294 | 0.1781++ | Trend Stationary[c] |

(continued on next page)

**Table B1** (*continued*)

| Shock | AR(1) Coefficient | ADF P-value[a] | KPSS Statistic[b] | Conclusion |
|---|---|---|---|---|
| Preference | −0.3736 | 0.0000*** | 0.2902 | Stationary |
| Investment | 0.1322 | 0.0000*** | 0.0855 | Stationary |
| Taylor Rule | 0.3915 | 0.0494** | $0.7264^{++}$ | Trend Stationary |
| Productivity | −0.3772 | 0.0416** | $0.7541^{+++}$ | Non-stationary[d] |
| Price mark-up | 0.1674 | 0.0079*** | $0.6376^{++}$ | Trend Stationary |
| Wage mark-up | 0.1258 | 0.0000*** | 0.2863 | Stationary |
| Labour supply | 0.3248 | 0.0000*** | 0.0744 | Stationary |
| Premium | 0.7726 | 0.0004*** | 0.0699 | Stationary |
| Net worth | −0.0780 | 0.0000*** | 0.1136 | Stationary |
| M0(crisis) | 0.3128 | 0.0000*** | $0.8033^{+++}$ | Trend Stationary |
| M0(noncrisis) | 0.3113 | 0.0000*** | $0.7934^{+++}$ | Trend Stationary |
| Export | 0.9234 | 0.0001*** | $0.1997^{++}$ | Trend Stationary |
| Import | 0.7643 | 0.0153** | $0.2017^{++}$ | Trend Stationary |

[a]For the Augmented Dickey-Fuller (ADF) test, ***, ** and * denote rejection of the unit root null at 1%, 5% and 10% significance levels, respectively.
[b]For the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test, $^{+++}$, $^{++}$ and $^{+}$ indicate rejection of the stationary null at 1%, 5% and 10% significance levels, respectively.
[c]These residuals are deemed trend stationary because their AR(1) coefficients are less than 1, suggesting that the impact of shocks diminish over time.
[d]Regarding the stationarity of the productivity residual for the post-1972 period, while the ADF test suggests it is stationary, the KPSS test rejects the null hypothesis of stationarity at the 1% significance level. For further clarity, we employed the DF-GLS test, which also indicates nonstationary. Hence, in light of both empirical results and theoretical consideration, we conclude that the productivity residual is non-stationary in the post-1972 period.

**Table B2**
Parameters fixed throughout study.

| Symbol | Description | Value | Source |
|---|---|---|---|
| $\beta$ | Quarterly discount rate | 0.990 | SW(07) |
| $\delta$ | Quarterly capital depreciate rate | 0.025 | SW(07) |
| $\theta$ | Survival rate of firms | 0.970 | BGG |
| $\gamma$ | Quarterly trend growth rate | 1.004 | SW(07) |
| $\epsilon_w$ | Kimball aggregator curvature for wages | 10.00 | SW(07) |
| $\epsilon_p$ | Kimball aggregator curvature for prices | 10.00 | SW(07) |
| $(1-\omega)$ | Home bias in consumption | 0.700 | Meenagh et al. (2010) |
| $(1-\omega^f)$ | Foreign equivalent of $\omega$ | 0.700 | Meenagh et al. (2010) |

## References


Alvarez, F., Beraja, M., Gonzalez-Rozada, M., Neumeyer, P.A., 2019. From hyperinflation to stable prices: Argentina's evidence on menu cost models. Q. J. Econ. 134 (1), 451–505.
Armington, P.S., 1969. A theory of demand for products distinguished by place of production (une théorie de la demande de produits différenciés d'après leur origine) (una teoría de la demanda de productos distinguiéndolos según el lugar de producción). Staff Papers (Int. Monetary Fund) 16 (1), 159–178. https://doi.org/10.2307/3866403, pp. 159-178.
Ascari, G., Florio, A., Gobbi, A., 2023. Price level targeting under fiscal dominance. J. Int. Money Financ. page 102876.
Beckworth, D., Hendrickson, J.R., 2020. Nominal GDP targeting and the Taylor rule on an even playing field. J. Money Credit Bank. 52 (1), 269–286.
Benchimol, J., 2024. Central bank objectives, monetary policy rules, and limited information. J. Macroecon. 80, 103604.
Benchimol, J., Fourçans, A., 2019. Central bank losses and monetary policy rules: a DSGE investigation. Int. Rev. Eco. Finance 61, 289–303.
Bernanke, B.S., Gertler, M., Gilchrist, S., 1999. The financial accelerator in a quantitative business cycle framework. Handb. Macroecon. 1, 1341–1393.
Bhandari, P., Frankel, J., 2017. Nominal GDP targeting for developing countries. Res. Econ. 71 (3), 491–506.
Bhattarai, S. and Egorov, K. (2016). Optimal monetary and fiscal policy at the zero lower bound in a small open economy. *Globalization and Monetary Policy Institute Working Paper*, (260).
Bhattarai, S., Schoenle, R., 2014. Multiproduct firms and price-setting: Theory and evidence from US producer prices. J. Monet. Econ. 66, 178–192.
Billi, R.M., 2017. A note on nominal GDP targeting and the zero lower bound. Macroecon. Dyn. 21 (8), 2138–2157.
Billi, R.M., 2020. Unemployment fluctuations and nominal GDP targeting. Econ. Lett. 188, 108970.
Blanchard, O., Dell Ariccia, G., Mauro, P., 2010. Rethinking macroeconomic policy. Revista De Economía Institucional 12 (22), 61–82.
Bunn, P., Ellis, C., 2012a. Examining the behaviour of individual UK consumer prices. Econ. J. 122 (558), F35–F55.
Bunn, P., Ellis, C., 2012b. How do individual UK producer prices behave? Econ. J. 122 (558), F16–F34.
Cajner, T., Crane, L. D., Decker, R. A., Grigsby, J., Hamins-Puertolas, A., Hurst, E., Kurz, C., and Yildirmaz, A. (2020). The US labor market during the beginning of the pandemic recession. National Bureau of Economic Research Working Paper 27159.
Calvo, G.A., 1983. Staggered prices in a utility-maximizing framework. J. Monet. Econ. 12 (3), 383–398.
Clarida, R., Galı, J., Gertler, M., 1998. Monetary policy rules in practice: some international evidence. Eur. Econ. Rev. 42 (6), 1033–1067.
Costain, J., Nakov, A., Petit, B., 2019. Monetary policy implications of state-dependent prices and wages. Banco De Espana Working Paper No 2272.
Costain, J., Nakov, A., Petit, B., 2022. Flattening of the phillips curve with state-dependent prices and wages. Econ. J. 132 (642), 546–581.
Davies, R. (2021). Prices and Inflation in the UK - A New Dataset. Centre for Economic Performance, London School of Economics and Political, Occasional Paper No.55.
Dedola, L., Kristoffersen, M. S., and Zullig, G. (2021). The extensive and intensive margin of price adjustment to cost shocks: Evidence from Danish multiproduct firms. Available at: https://gabrielzuellig.ch/wp-content/uploads/2021/04/CostPassthrough.pdf.

Dickens, W.T., Goette, L., Groshen, E.L., Holden, S., Messina, J., Schweitzer, M.E., Turunen, J., Ward, M.E., 2007. How wages change: micro evidence from the international wage flexibility project. J. Econ. Perspect. 21 (2), 195–214.
Dixon, H., Luintel, K., Tian, K., 2020. The impact of the 2008 crisis on UK prices: what we can learn from the CPI microdata. Oxf. Bull. Econ. Stat. 82 (6), 1322–1341.
Dong, X., Minford, P., Meenagh, D., 2019. How important are the international financial market imperfections for the foreign exchange rate dynamics: a study of the sterling exchange rate. J. Int. Money Financ. 94, 62–80.
Dotsey, M., King, R.G., Wolman, A.L., 1999. State-dependent pricing and the general equilibrium dynamics of money and output. Q. J. Econ. 114 (2), 655–690.
Engel, C. and West, K. D. (2004). Taylor rules and the Deutschmark-Dollar real exchange rate. National Bureau of Economic Research Working Paper No 10995.
Fackler, J.S., McMillin, W.D., 2020. Nominal GDP versus price level targeting: an empirical evaluation. J. Econ. Bus. 109, 105890.
Fair, R.C., Taylor, J.B., 1980. Solution and maximum likelihood estimation of dynamic nonlinear rational expectations models. National Bureau of Economic Research Working Paper No 0005.
Falagiarda, M., 2014. Evaluating quantitative easing: a DSGE approach. Int. J. Monetary Eco. Finance 7 (4), 302–327.
Gagnon, E., 2009. Price setting during low and high inflation: evidence from mexico. Q. J. Econ. 124 (3), 1221–1263.
Gali, J., Monacelli, T., 2005. Monetary policy and exchange rate volatility in a small open economy. Rev. Econ. Stud. 72 (3), 707–734.
Garín, J., Lester, R., Sims, E., 2016. On the desirability of nominal GDP targeting. J. Econ. Dyn. Control. 69, 21–44.
Gasteiger, E. and Grimaud, A. (2020). Price setting frequency and the phillips curve. ECON WPS, No. 03/2020, Vienna University of Technology, Institute of Statistics and Mathematical Methods in Economics, Research Group Economics, Vienna.
Giavazzi, F., Giovannini, A., 1989. Monetary policy interactions under managed exchange rates. Economica 199–213.
Grajales, A., Uras, B., and Vellekoop, N. (2019). Rigid wages and contracts: Time-versus state-dependent wages in the netherlands. CentER Discussion Paper Series No. 2019-027, Available at SSRN: https://ssrn.com/abstract=3447825 or https://doi.org/10.2139/ ssrn.3447825.
Grigsby, J., Hurst, E., Yildirmaz, A., 2021. Aggregate nominal wage adjustments: New evidence from administrative payroll data. Am. Econ. Rev. 111 (2), 428–471.
Hatcher, M. (2016). Nominal GDP targeting and the tax burden. University of Southampton Working Paper No. 1604.
Hendrickson, J.R., 2012. Nominal income targeting and monetary stability. In: Beckworth, D. (Ed.), *Boom and Bust Banking: the Causes and Cures of the Great Recession*. Independent Institute, Oakland, CA.
Konieczny, J.D., Skrzypacz, A., 2005. Inflation and price setting in a natural experiment. J. Monet. Econ. 52 (3), 621–632.
Le, V.P.M., Meenagh, D., Minford, P., 2016a. Monetarism rides again? US monetary policy in a world of Quantitative Easing. J. Int. Financ. Mark. Inst. Money 44, 85–102.
Le, V.P.M., Meenagh, D., Minford, P., 2021. State-dependent pricing turns money into a two-edged sword: a new role for monetary policy. J. Int. Money Financ. 119, 102496.
Le, V. P. M., Meenagh, D., and Minford, P. (2023). Could an economy get stuck in a rational pessimism bubble? The case of Japan. Cardiff Economics Working Papers E2023/13, Cardiff University, Cardiff Business School, Economics Section.
Le, V.P.M., Meenagh, D., Minford, P., Wang, Z., 2024. UK monetary and fiscal policy since the great recession-an evaluation. Appl. Econ. 1–29. https://doi.org/10.1080/00036846.2024.2393897.
Le, V.P.M., Meenagh, D., Minford, P., Wickens, M., 2011. How much nominal rigidity is there in the US economy? Testing a New keynesian DSGE Model using indirect inference. J. Econ. Dyn. Control. 35 (12), 2078–2104.
Le, V. P. M., Meenagh, D., Minford, P., and Wickens, M. (2015). Small sample performance of indirect inference on DSGE models. CEPR Press Discussion Paper No. 10382. https://cepr.org/publications/dp10382.
Le, V.P.M., Meenagh, D., Minford, P., Wickens, M., Xu, Y., 2016b. Testing macro models by indirect inference: a survey for users. Open Econ. Rev. 27, 1–38.
Le, V.P.M., Minford, P., Wickens, M., 2010. The 'Puzzles' methodology: en route to indirect inference? Econ. Model. 27 (6), 1417–1428.
Lyu, J., Le, V.P.M., Meenagh, D., Minford, P., 2023. UK monetary policy in an estimated DSGE model with financial frictions. J. Int. Money Financ. 130, 102750.
Meenagh, D., Minford, P., Nowell, E., Sofat, P., 2010. Can a Real Business Cycle Model without price and wage stickiness explain UK real exchange rate behaviour? J. Int. Money Financ. 29 (6), 1131–1150.
Meenagh, D., Minford, P., and Wickens, M. (2012). Testing macroeconomic models by indirect inference on unfiltered data. CEPR Discussion Paper No. DP9058, Available at SSRN: https://ssrn.com/abstract=2153509.
Meenagh, D., Minford, P., Wickens, M., Xu, Y., 2019. Testing DSGE models by indirect inference: a survey of recent findings. Open Econ. Rev. 30, 593–620.
Millard, S., Tatomir, S., 2015. Firms' Adjustment during 2010–13: Evidence from the Wage Dynamics Survey. Bank of England Working Paper, No. 568.
Minford, L., Meenagh, D., 2020. Supply-side policy and economic growth: a case study of the UK. Open Econ. Rev. 31, 159–193.
Minford, P., Agenor, P.-R., Nowell, E., 1986. A new classical econometric model of the world economy. Econ. Model. 3 (3), 154–174.
Minford, P., Marwaha, S., Matthews, K., Sprague, A., 1984. The Liverpool macroeconomic model of the United Kingdom. Econ. Model. 1 (1), 24–62.
Minford, P., Matthews, K., Marwaha, S., 1979. Terminal conditions as a means of ensuring unique solutions for rational expectations models with forward expectations. Econ. Lett. 4 (2), 117–120.
Minford, P., Ou, Z., Zhu, Z., 2021. Can a small New keynesian model of the world economy with risk-pooling match the facts? Int. J. Finance Eco. 26 (2), 1993–2021.
Minford, P., Ou, Z., Zhu, Z., 2022. Is there consumer risk-pooling in the open economy? the evidence reconsidered. Open Econ. Rev. 33 (1), 109–120.
Minford, P., Theodoridis, K., Meenagh, D., 2009. Testing a model of the UK by the method of indirect inference. Open Econ. Rev. 20, 265–291.
Nakamura, E., Steinsson, J., Sun, P., Villar, D., 2018. The elusive costs of inflation: Price dispersion during the US great inflation. Q. J. Econ. 133 (4), 1933–1980.
Nasir, M.A., 2021. Zero lower bound and negative interest rates: choices for monetary policy in the UK. J. Policy Model. 43 (1), 200–229.
Nilsen, Ø.A., Pettersen, P.M., Bratlie, J., 2018. Time-dependency in producers' price adjustments: evidence from micro panel data. Rev. Eco. 69 (2), 147–168.
Petrella, I., Santoro, E., and de la Porte Simonsen, L. (2018). Time-varying price flexibility and inflation dynamics. CEPR Discussion Paper No. DP13027, Available at SSRN: https://ssrn.com/abstract=3206793.
Portes, J., Wren-Lewis, S., 2015. Issues in the design of fiscal policy rules. Manch. Sch. 83, 56–86.
Praščević, A., Ješić, M., 2019. Modelling macroeconomic policymakers' interactions under zero lower bound environment: the new keynesian theoretical approach. J. Central Banking Theory and Practice 8 (1), 5–38.
Rudolf, B. and Seiler, P. (2022). Price setting before and during the pandemic: evidence from Swiss consumer prices. ECB Working Paper No. 2022/2748, Available at SSRN: https://ssrn.com/abstract=4277190 or https://doi.org/10.2139/ssrn.4277190.
Sigurdsson, J., Sigurdardottir, R., 2016. Time-dependent or state-dependent wage-setting? evidence from periods of macroeconomic instability. J. Monet. Econ. 78, 50–66.
Smets, F., Wouters, R., 2007. Shocks and frictions in US business cycles: a Bayesian DSGE approach. Am. Econ. Rev. 97 (3), 586–606.
Smith, A.A., 1993. Estimating nonlinear time-series models using simulated vector autoregressions. J. Appl. Economet. 8 (S1), S63–S84.
Sumner, S., 2012. The case for nominal GDP targeting. Mercatus Research.
Takahashi, S., 2018. State dependency in price and wage setting. *47th Issue (february 2017) of the International Journal of Central Banking*.
Taylor, J.B., 1995. The monetary transmission mechanism: an empirical framework. J. Econ. Perspect. 9 (4), 11–26.
Wang, J. and Wu, J. J. (2009). The Taylor rule and interval forecast for exchange rates. Available at: https://www.federalreserve.gov/econres/ifdp/the-taylor-rule-andinterval-forecast-for-exchange-rates.htm.
Woodford, M., 2012. Methods of policy accommodation at the interest-rate lower bound. Federal Reserve Bank of Kansas City 185–288.
Wulfsberg, F., 2016. Inflation and price adjustments: micro evidence from norwegian consumer prices 1975–2004. Am. Econ. J. Macroecon. 8 (3), 175–194.
Zhou, P., Dixon, H., 2019. The determinants of price rigidity in the UK: Analysis of the CPI and PPI microdata and application to macrodata modelling. Manch. Sch. 87 (5), 640–677.