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Can Modern Monetary Theory fit the post-Crisis US facts? Evidence from a full DSGE model

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Abstract

Modern Monetary Theory (MMT) claims that a monetarily sovereign government like the US is never confronted by a real budget constraint since it can always monetise any deficit by printing money; and this need not be inflationary since it can always drain excess money from circulation by taxing. MMT economists claim that their theory is in line with the behaviour of the US data since the Financial Crisis, and argue that policy in the post-COVID recovery period should continue to be guided by MMT principles. We set out the MMT policy rules within a full DSGE model and test this model version against the data by indirect inference, side by side with a standard New Keynesian rival version, to evaluate these claims. We find that the MMT model is rejected by the data, while the standard model is not; and that the MMT policy rules imply a material loss of welfare compared to the standard ones.

KEYWORDS

DSGE model, fiscal activism, indirect inference, Modern Monetary Theory, Wald test

1 | INTRODUCTION

The past decade since the global Financial Crisis has seen conventional monetary policy losing traction and fiscal policy stimulus frustrated by fears about long-run solvency, which gave rise to policies of 'austerity' generally supported by mainstream economists. However, during the Covid crisis such fears were set on one side as developed country governments pursued policies of massive fiscal support, accompanied by very large expansions of the monetary base and also the broader money supply. A rising group of political activists and 'heterodox' economists has strongly supported such policies not merely for the Covid emergency but also for normal times—their views are known as Modern Monetary Theory (MMT), a school of thought largely ignored by the mainstream since its creation in the 1990s, but which has recently spread much more widely (especially via blogs and social media posts) and attracted many followers. As Colander (2019) has commented, the marketing success of MMT has made it part of the mainstream conversation to which mainstream economists have felt compelled to respond. The fact that MMT is quoted (whether more explicitly or less so) in many recent discussions of policy proposals, such as the Green New Deal and Job Guarantee, and even the latest ones related to post-COVID recovery, speaks for itself, and underlines the need to give this theory a careful evaluation.

The fundamental distinction of MMT from the New Keynesian theory which has dominated macro policy analyses for nearly three decades lies in its view of the nature of money and what this means for the government's capacity to pursue fiscal policy. Thus, instead of seeing money as a 'medium of exchange', MMT economists argue that money derives its fundamental value from being a 'unit of account' imposed by the government requiring taxes to be paid in a designated currency.[1] Thus, a monetarily sovereign government—being the monopoly issuer of that currency—would never be confronted by a 'budget constraint'. As long as the government does not attempt to consume more than what is available in the economy (i.e., its consumption does not breach the real resource constraint), it would always be able to finance its own spending by 'printing' as much money as needed.

MMT portrays a world in which fiscal activism is possible because the fiscal authority enjoys much more space than mainstream models would predict. If the fiscal authority could never run out of money, this would be a welcome addition to the set of policy instruments available to manage the economy, since fiscal instruments—which generally have strong direct impacts—could be used whenever needed; and fiscal policy is easier to implement in low-interest environments (as in the US and EU post-Crisis), and in economies where monetary transmission remains inefficient (as in most developing economies). The problem of concern to macroeconomists, however, is: 'how can inflation be stabilised if money can be printed freely to finance public deficits?'

According to MMT, inflation is stabilized by taxes. Thus, another key distinction of MMT from conventional monetary theories (such as the New Keynesian theory) lies in the role of taxes. MMT economists argue that, since the government can print as much money as it needs, taxes are no longer needed for financing spending; instead, they are levied by the government, and must be paid in the currency it has issued, for the sole purpose of draining money from circulation; in this way excess money can be 'burnt', as an 'inflation-avoidance manoeuvre' (Wray, 2019). Thus taxes, which control the supply of money in the MMT world, are an inflation management tool (Armstrong, 2019; Mitchell et al., 2019; Murphy, 2019; Wray, 2019).

The policy regime in the MMT world can therefore be described in the following way: government spending stabilizes output (or employment); money is created to finance such spending at interest rates held down by limiting government borrowing; money thus enters circulation; taxes, which stabilize inflation, are then levied to drain it from the economy so that the quantity in circulation delivers the inflation target in the steady state. MMT claims that this mechanism is in line with what was observed in the post-Crisis era of the US during which public debt continued to swell and quantitative easing (QE) injected a huge amount of money, while inflation remained moderate (Davies, 2019). Wray (2019, p.10) further claims that: '*This is the way it has worked for the past 4000 years... in spite of the modern procedures adopted*'.

However, no MMT contribution has so far spelt out this narrative as a model in a testable form. This prevents MMT from taking its theory beyond blogs and social media posts to convince the profession at large, for which therefore the rosy picture it describes for fiscal activism remains both vague and unconvincing. On the other hand, other economists have so far also not been able to assess MMT formally using standard statistical/modelling methods. Without this analysis, we lack formal evidence on whether the policies advocated by MMT would achieve what it claims.

This is the gap in the literature we aim to fill here. Thus, in this paper we construct an MMT model side by side with a standard New Keynesian (NK) model inclusive of an explicit demand for money for comparability with the MMT model.[2] We treat this NK model, which is widely recognized as the standard workhorse for macro policy analyses, as the benchmark model for evaluation against the MMT model. The MMT model differs from this benchmark NK model by replacing the Taylor rule with an explicit money supply function implied by the MMT description of monetary policy, namely, (a) money is issued to finance government spending not covered by taxes or bond issues, where (b) bond issues are made to keep nominal interest rates close to an interest rate target, and (c) taxes are levied to meet an inflation target. Hence the money supply responds positively both to government deficits and to nominal interest rates which it aims to stabilize, and negatively to inflation above target. This creates a monetary regime quite distinct from the Taylor rule, enabling us to distinguish the behaviour of the two otherwise identical models.

We set up these rival models with the objective of testing the key propositions, which appear to be two-fold, put forward by the MMT school: first, over the period since the Financial Crisis the operation of monetary policy in controlling interest rates and issuing currency via QE has been best described by the money policy functions of the MMT model rather than by the Taylor rule of the benchmark model; second, monetary policy would better stabilize the economy if it is carried out in the MMT manner—that is, monetary policy coordinates with fiscal policy to create policy space for the latter, through deficit monetisation—than by pursuing monetary independence with a Taylor rule. We test both these propositions here, the first by indirect inference against the data since the Crisis where we ask if any model can pass a Wald test of the data's behaviour with a high-enough probability[3]; the second by stochastic simulations of the economy under both regimes.

We find that, while the benchmark NK model passes the indirect inference Wald test comfortably, the MMT model is clearly rejected. Since the two models only differ in how monetary policy operates within them, effectively this is a rejection of the monetary behaviour described by MMT economists; by contrast, the Taylor rule remains a robust abstraction of the true behaviour of the Fed. Compared to the Taylor rule regime, monetary-fiscal policy coordination advocated by MMT economists would bring no gain in inflation and real interest rate stability; however, it would destabilize output substantially, jeopardizing macro stability overall and diminishing household welfare.

Our two-fold contribution in this paper comes both from its approach and its findings. Thus, by constructing a full DSGE model with policies governed by the principles of MMT, we are the first to spell out this theory, which is so far nothing more than a lax composite of statements about the working of the modern monetary system, as an explicit, mathematical model characterized by a full set of behavioural and policy equations, which is fully assessable and testable; as we evaluate the model with a formal statistical test and stochastic simulations, we provide the first piece of model- and data-based evidence about the empirical validity of MMT, which has never been available before. Then, our finding that MMT neither explains how the transmission mechanism works nor points a viable way forward for future reforms of monetary and fiscal policies is strong evidence against this theory despite its recent popularity, especially as it is quoted by many discussions of policy proposals—in this sense, we are echoed by Drumetz and Pfister (2021) that, the theory is more like 'a political manifesto' than a genuine economic theory.

In the remainder of this paper: we set out the benchmark NK model and its MMT variant in Section 2; in Section 3 we explain the indirect inference method for testing DSGE models and report the test results; in Section 4 we analyse the data using the 'true' model as informed by the test; in Section 5 we compare the implications on stability and welfare under the benchmark and MMT models; Section 6 concludes.

2 | MODEL

2.1 | The benchmark model

Our benchmark model is a standard New Keynesian model with money, which consists of three sectors: households, firms (including capital producers), and the public sector. Households consume and work; firms hire labour and capital, and produce goods which are sold at the retail level following Calvo pricing; capital producers build capital, and sell it to households who then rent it to firms; the public sector consists of a central bank managing nominal interest rates and a fiscal authority managing government spending and taxes; money is introduced by assuming money-in-utility.

Since the aim of our research does not require that the detailed working of the Zero Lower Bound must be modelled explicitly, for convenience we bypass the ZLB problem by treating the corporate bond yield (which never hit the bound) as the target of monetary policy via any instruments it chooses—whether the short-term interest rates or QE; thus, we assume that monetary policy is throughout focused on influencing credit conditions, doing so by setting short-term rates on government bonds when the rates are above zero, and switching to asset purchases and QE when the rates are near the ZLB. This treatment allows us to avoid complicating our model unnecessarily while ensuring that the simplification does not undermine our investigation; for recent examples where the same approach is adopted, see Minford et al. (2021, 2022). As will be seen in Section 3, this theoretical assumption is supported by the data.[4]

The detailed structure of the benchmark model is outlined below. The first order conditions are listed in the Appendix.

2.1.1 | Households

Households are assumed to consume, work, hold money and save; and they buy capital from capital producers, rent it to firms, and resell the undepreciated portion back to capital producers at the end of each period. Households own all profits of the economy. They have life-time utility:

$$U_0 = E_0 \sum_{t=0}^{\infty} \beta^t j_t \left\{ \Gamma ln(c_t - \vartheta c_{t-1}) + \chi ln m_t - \psi \frac{n_t^{1+\eta}}{1+\eta} \right\}, \tag{1}$$

where c_t is the real consumption, m_t is the real money holding, n_t is the labour hour, η is the inverse of the wage elasticity, χ and ψ are the preferences for money and leisure relative to consumption, ϑ is the habit persistence in consumption, Γ is a scaling factor,[5] β is the discount factor, and j_t is the time preference shock. The household budget constraint is:

$$c_t + s_t + m_t + q_t k_t = (1-\tau_t) w_t n_t + (1+r_{t-1}) s_{t-1} + \frac{m_{t-1}}{1+\pi_t} + tr_t + r_{k,t} k_{t-1} + q_t (1-\delta) k_{t-1} + \Pi_{y,t} + \Pi_{k,t} \tag{2}$$

where s_t is the real savings, τ_t is the tax rate on wage income, w_t is the real wage rate, r_{t-1} is the lagged real interest rate, π_t is the inflation rate, tr_t is the real money balance transferred from the public sector, q_t and $r_{k,t}$ are the sales and rental prices of capital, k_t is end-of-period capital stock, δ is the rate of capital depreciation, $\Pi_{y,t}$ and $\Pi_{k,t}$ are the real profits transferred from firms and capital producers, respectively.

The household problem is to maximize (1) subject to (2) by choosing c_t, m_t, n_t, s_t and k_t. The first order conditions determine the demand for goods, money and capital, and the supply of labour; the budget constraint determines the demand for deposits.

2.1.2 | Firms

Firms produce with the following technology:

$$y_t = z_t n_t^{1-u} k_{t-1}^u, \tag{3}$$

where y_t is output, z_t is productivity, u is the capital share.

The intermediate goods market is perfectly competitive. The optimisation problem faced by firms in this market is to minimize the cost of production $TC_t = w_t n_t + r_{k,t} k_{t-1}$ by choosing n_t and k_{t-1}. The first order conditions imply the optimal substitution between labour and capital (expressed here as the demand for labour):

$$n_t = \frac{1-u}{u} \frac{r_{k,t}}{w_t} k_{t-1}, \tag{4}$$

and the real marginal cost of production:

$$mc_t = \frac{1}{z_t} \left(\frac{1}{u}\right)^u \left(\frac{1}{1-u}\right)^{1-u} w_t^{1-u} r_{k,t}^u, \tag{5}$$

The intermediate goods are then differentiated by firms in the retail market, which is monopolistically competitive, at no extra cost. The standard Calvo (1983) pricing strategy allowing for partial inflation indexation (Christiano et al., 2005) in the profit maximization problem implies the New Keynesian Phillips curve:

$$\widehat{\pi}_t = \frac{\beta\Omega}{1+\beta\epsilon\Omega} E_t \widehat{\pi}_{t+1} + \frac{\epsilon}{1+\beta\epsilon\Omega} \widehat{\pi}_{t-1} + \frac{(1-\omega)(1-\omega\beta\Omega)}{\omega(1+\beta\epsilon\Omega)} \widehat{mc}_t + \widehat{\varepsilon}_{\pi,t}, \tag{6}$$

which relates inflation to expected future inflation, past inflation, and real marginal costs ('^' denotes the percentage deviation of a variable from its steady-state value). $1-\omega$ is the fraction of retailers who are able to reset an optimal price. ϵ is the degree of inflation indexation adopted by those who are unable to reoptimise. $\Omega \equiv (1+\overline{\pi})^{(\theta-1)(1-\epsilon)}$ where $\overline{\pi}$ is the steady-state level of inflation and θ is the price elasticity of demand. $\widehat{\varepsilon}_{\pi,t}$ is the price mark-up shock.

The retail firm profit, which is transferred to households as a lump-sum, is:

$$\Pi_{y,t} = (1-mc_t) y_t, \tag{7}$$

where the real price of goods is normalized to unity.

2.1.3 | Capital producers

Capital producers invest to build capital in the following law of motion:

$$k_t - k_{t-1} = \varepsilon_{i,t} \left[i_t - \frac{F}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 i_t \right] - \delta k_{t-1}, \tag{8}$$

where i_t is the real investment, $\frac{F}{2}\left(\frac{i_t}{i_{t-1}}-1\right)^2 i_t$ is the capital adjustment cost, $\varepsilon_{i,t}$ is the shock to investment efficiency. The optimisation problem of capital producers is to maximize life-time profit $E_0 \sum_{t=0}^{\infty} \beta^t V_{0,t} \Pi_{k,t}$ by choosing i_t, subject to (8), which determines the supply of capital.

The lump-sum profit transferred to households in each period is:

$$\Pi_{k,t} = q_t k_t - q_t (1-\delta) k_{t-1} - i_t, \tag{9}$$

2.1.4 | The public sector

The public sector is constituted by a central bank and a fiscal authority.

The central bank stabilizes output and inflation by adjusting the nominal interest rate following a Taylor rule:

$$1+R_t = (1+R_{t-1})^{\rho_R}\left(\frac{1+\pi_t}{1+\pi^*}\right)^{(1-\rho_R)\varphi_\pi}\left(\frac{y_t}{\bar{y}}\right)^{(1-\rho_R)\varphi_x} \left(1+\overline{R}\right)^{(1-\rho_R)}\varepsilon_{TR,t}, \tag{10}$$

where R_t is the policy rate, ρ_R is the policy inertia, φ_π and φ_x are the interest rate responses to inflation and output, π^* is the inflation target, $\bar{y}$ and $\overline{R}$ are the steady-state levels of output and the policy rate, $\varepsilon_{TR,t}$ is the shock to monetary policy.

The fiscal authority stabilizes output and public debt by adjusting government spending, g_t, following:

$$g_t = \varepsilon_{g,t}\bar{g}\left(\frac{y_t}{\bar{y}}\right)^{\gamma_x}\left(\frac{b_{t-1}}{\bar{b}}\right)^{\gamma_b}, \tag{11}$$

where b_{t-1} is the debt outstanding, γ_x and γ_b are the policy responses to output and debt, $\bar{g}$ is the steady-state-level government spending, $\varepsilon_{g,t}$ is the government spending shock. It also stabilizes by taxing, by adjusting the marginal tax rate on wage income in a similar manner:

$$(1+\tau_t) = \varepsilon_{\tau,t}(1+\bar{\tau})\left(\frac{y_t}{\bar{y}}\right)^{\phi_x}\left(\frac{b_{t-1}}{\bar{b}}\right)^{\phi_b}, \tag{12}$$

where ϕ_x, ϕ_b and $\bar{\tau}$ have similar meanings, and $\varepsilon_{\tau,t}$ is the shock to the tax policy.

Tax revenue, t_t, is given by:

$$t_t = \tau_t w_t n_t, \tag{13}$$

The standard government budget constraint is given by:

$$g_t - t_t = \Delta b_t - r_{t-1}b_{t-1} + h_t - tr_t, \tag{14}$$

which requires the primary deficit to be met by the new issuing of debt, plus real money creation (h_t), net of the interest payment on the previous debt outstanding and the real money balance transferred to households. For simplicity, we impose that the government never monetises its deficits such that all the newly created money is transferred to households, hence $h_t = tr_t$; this money creation satisfies the demand for high-powered money, which we assume is related to the demand for money by a money multiplier relationship. This simplification whereby the transfer equals the money creation therefore implies $g_t - t_t = \Delta b_t - r_{t-1}b_{t-1}$, such that effectively the government budget constraint takes the same form as the ones in standard NK models without money.

2.1.5 | Market clearing, identities and shock processes

The goods market clears with:

$$c_t + i_t + g_t = y_t, \tag{15}$$

The bond market clears with:

$$s_t = b_t, \tag{16}$$

The real interest rate is defined by the Fisher equation:

$$1+r_t = \frac{1+R_t}{1+E_t\pi_{t+1}}, \tag{17}$$

The real money stock in circulation is given by:

$$m_t = \frac{m_{t-1}}{1+\pi_t} + h_t, \tag{18}$$

All the shocks are mean-reversing and the logs of them are AR(1) processes.

2.2 | The MMT model variant

In the benchmark model above, government spending is financed by tax revenue and public debt; money is issued by the central bank 'independently' according to the bank's own targets. Central bank independence in such a setting requires that government spending must be 'Ricardian'—that is, the current primary deficit must be equal to the present value of expected future primary surpluses—such that the government budget is solvent intertemporally and that the central bank is not forced to monetise any deficit (or debt) which would be inflationary according to the familiar logic of 'unpleasant monetarist arithmetic' (Sargent & Wallace, 1981). As will be seen, given the various rules that impact on the issuing of money under MMT, the government is still constrained to follow a Ricardian policy. Nevertheless, with part of the deficit being monetised directly, long-run solvency will require an 'inflation tax'—implying an inflation equilibrium—though under reasonable inflation targets the discipline will be not much affected.

Thus under MMT government spending still aims at stabilizing output (or 'full employment' as described in most MMT narratives). But monetary policy, instead of being bound by the central bank's benchmark interest rate rule, is essentially accommodative in the short run: the supply of cash is determined as whatever is needed to finance the government's budget. Furthermore, interest rates are held down to a target value by limiting the issuing of debt, which correspondingly increases the cash issue. Finally, taxes, which must be paid with money, are manipulated to hit an inflation target by absorbing any excess money creation threatening excess long run inflation.[7]

Our MMT variant of the benchmark model therefore features the following modifications: (a) fiscal deficits drive the supply of money—hence monetary policy loses its direct role in stabilizing inflation; (b) inflation is stabilized by the marginal tax rate on wages; (c) debt is no longer determined by the government budget constraint (which is now effectively a money supply equation); instead, it is adjusted for delivering a desired level of the nominal rate of interest. Effectively, this means that monetary policy under MMT takes the form of a complex money supply process resulting from (a) to (c) in place of the New Keynesian Taylor rule for interest rates; interest rates in turn are set by money market equilibrium.

The first modification involves rewriting the government budget constraint to be:

$$h_t = g_t - t_t - \Delta b_t + r_{t-1} b_{t-1}, \tag{19}$$

such that the net increase in real money balance is determined by the shortfall of the government budget given the tax revenue and debt outstanding. In this model we assume that all the newly created money is used for financing the government's own deficits—a mechanism of 'automatic deficit monetisation'; accordingly there is no real balance transfer to households. Since the central bank is now consolidated with the fiscal authority into a single entity, this equation replaces the Taylor rule in the benchmark model.

The second modification involves rewriting the tax policy rule to be:

$$1+\tau_t = \varepsilon_{\tau,t}(1+\overline{\tau})\left(\frac{1+\pi_t}{1+\pi^*}\right)^{\phi_\pi}, \tag{20}$$

such that the tax rate is now adjusted to stabilize inflation, instead of output and debt.

The third modification involves adding a debt supply rule:

$$b_t = \varepsilon_{b,t}\overline{b}\left(\frac{1+R_t}{1+\overline{R}}\right)^{\varsigma}, \tag{21}$$

where debt stabilizes the nominal interest rate (with $\varsigma < 0$) around the target level, and $\varepsilon_{b,t}$ is the debt supply shock. As the MMT school argues, debts in the MMT world—which are otherwise not necessary—are only needed for preventing excess reserves in the banking system from pushing nominal interests to zero (Ehnts & Höfgen, 2019); hence, it is an interest rate management tool. Accordingly the government spending rule is modified to be:

$$g_t = \varepsilon_{g,t}\overline{g}\left(\frac{y_t}{\overline{y}}\right)^{\gamma_x}, \tag{22}$$

such that it no longer stabilizes debt outstanding.

It is not difficult to see that under this setting long-run solvency is guaranteed by $\overline{b} \approx \frac{1}{\overline{r}}\left(\overline{t} - \overline{g} + \overline{m}\frac{\overline{\pi}}{1+\overline{\pi}}\right)$, that is, the steady-state outstanding debt is approximately equal to the present value of the 'permanent' primary surplus embracing an inflation tax, as in any standard model where government spending is partly money financed.[8] Nevertheless, since (20) requires the tax rate to keep adjusting until the inflation target is hit, given a reasonable target, say 2%, and the fact that $\overline{m}$ has a similar size as $\overline{g}$, the steady-state inflation tax, $\overline{m}\frac{\overline{\pi}}{1+\overline{\pi}}$, would be so small that it would hardly affect the discipline. Hence from a long-term viewpoint MMT can still be quite disciplinarian on deficits in spite of the ongoing monetisation. What the regime has essentially changed is the short-run dynamics of monetary policy, by linking it to fiscal policy, interest rates and inflation.

2.3 | How do the two models differ in their behaviour?

Before moving forward to evaluate the models' fit, we review how the behaviour of the two models differs under the different policy settings. Since the fundamental difference between MMT and the benchmark NK model lies in the former's replacement of the Taylor rule with a money supply function driven by public deficits (thus, the replacement of (10) with (19) in our modelling above), we illustrate how the transmission differs given a shock to the primary deficit, through government spending or the tax rate on wages. In another helpful illustration we compare how policy instruments react under the two regimes to a demand shock, such as the consumption preference shock. We parameterise both models with an identical set of standard parameter values that we estimate (as set out in detail in Section 3.3) below; and compute the effect of a one-standard-deviation shock in all cases.

Figure 1 compares the key impulse responses caused by a government spending shock. As the figure shows, a rise in government spending under the benchmark model drives up output and inflation, leading to a rise in the

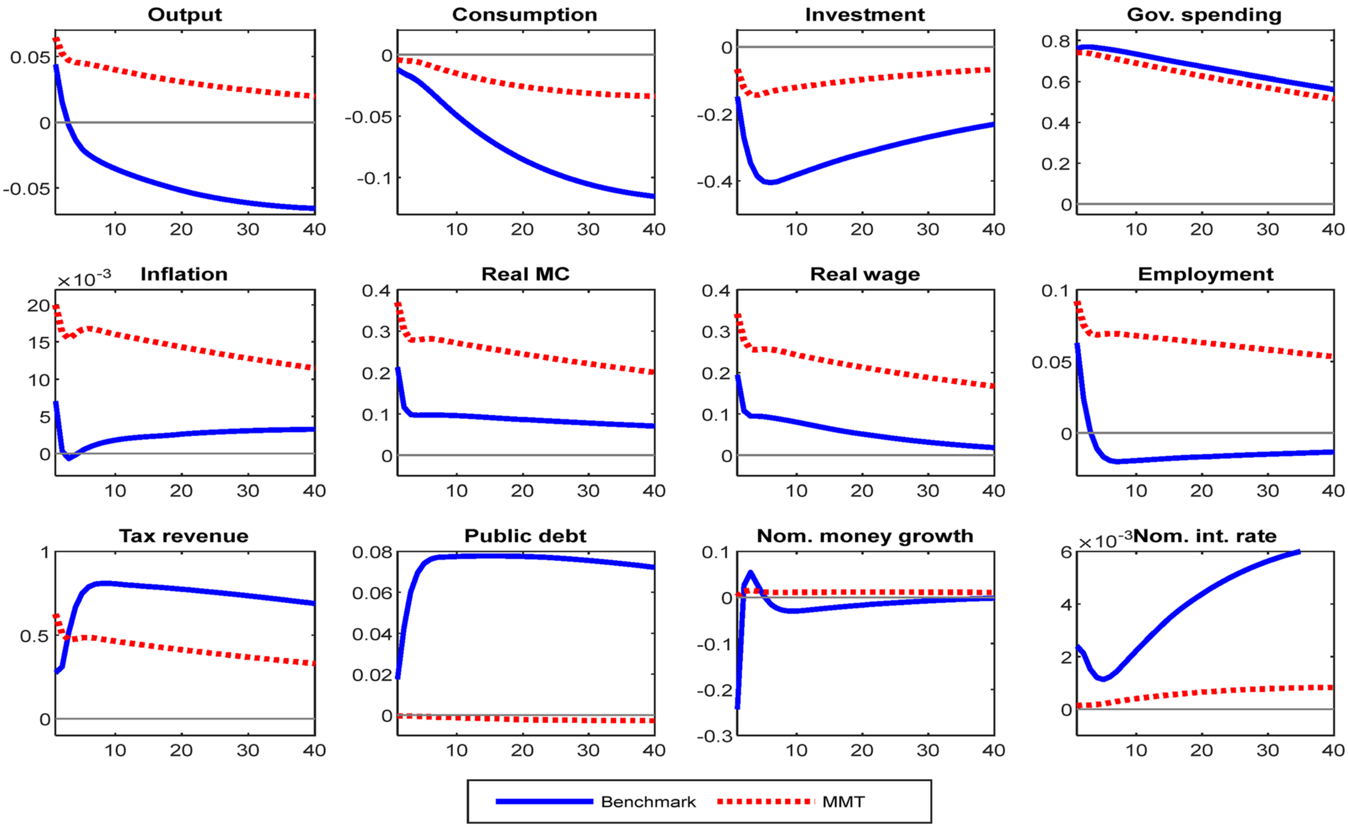

FIGURE 1 Effect of a rise in government spending. [Colour figure can be viewed at wileyonlinelibrary.com]

nominal interest rate—made to happen via a reduced money supply—enforced by the Taylor rule; public debt rises to finance the budget deficit due to the insufficient rise in tax revenue. These 'orthodox' responses are in sharp contrast to those under MMT, where although the rise in government spending still drives up output and inflation and causes tax revenue to rise,[9] money—instead of debt—has to rise to finance the deficit as it emerges, as under MMT debt does not respond to the deficit directly. Such a rise in money does not lead to a fall in the nominal interest rate, as it shows; rather, as the initial rise in output and inflation triggers a strong rise in money demand, the nominal interest rate rises to clear the market, which mimics the Taylor rule's behaviour. Hence, under MMT monetary policy enforces through the money supply some indirect raising of interest rates as the Taylor rule does; but this 'indirect monetary tightening' is much weaker and more gradual and as a result, the output boost lasts much longer.

Figure 2 compares the effect of a tax cut on wages. This encourages work participation in both models, causing the real wage (hence also the real marginal cost) to fall; and supply (output) rises. Under the benchmark model, the nominal interest rate falls initially in response to lower prices due to the Taylor rule; but rebounds quickly, as inflation emerges as demand is stimulated. The ultimate rise in the interest rate, implying a fall in money supply, crowds out sufficient consumption and investment finally, which ends the output boost. By contrast, under MMT the nominal interest rate can fall only, as money supply has to rise in response to the tax cut since the reduction in fiscal revenue cannot be filled by the issuing of public debt. Hence, output is boosted further with a surge in both consumption and investment. On this occasion, the demand side always dominates the supply side, such that the inflation response is always positive and the surge in it is much more substantial than under the benchmark model.

In sum, fiscal expansion—whether via a rise in government spending or a tax cut on wages—results in much larger output multipliers at the expense of more inflation under MMT which, by forcing money to finance such expansion, implies a much more permissive money supply process—as might be expected from the thrust of MMT policy advice.

Figure 3 shows how the policy instruments respond to a straight demand shock (due to a rise in consumption preference) under the two regimes. The shock increases consumption and output directly, which elicits three policy responses: two are fiscal, where government spending

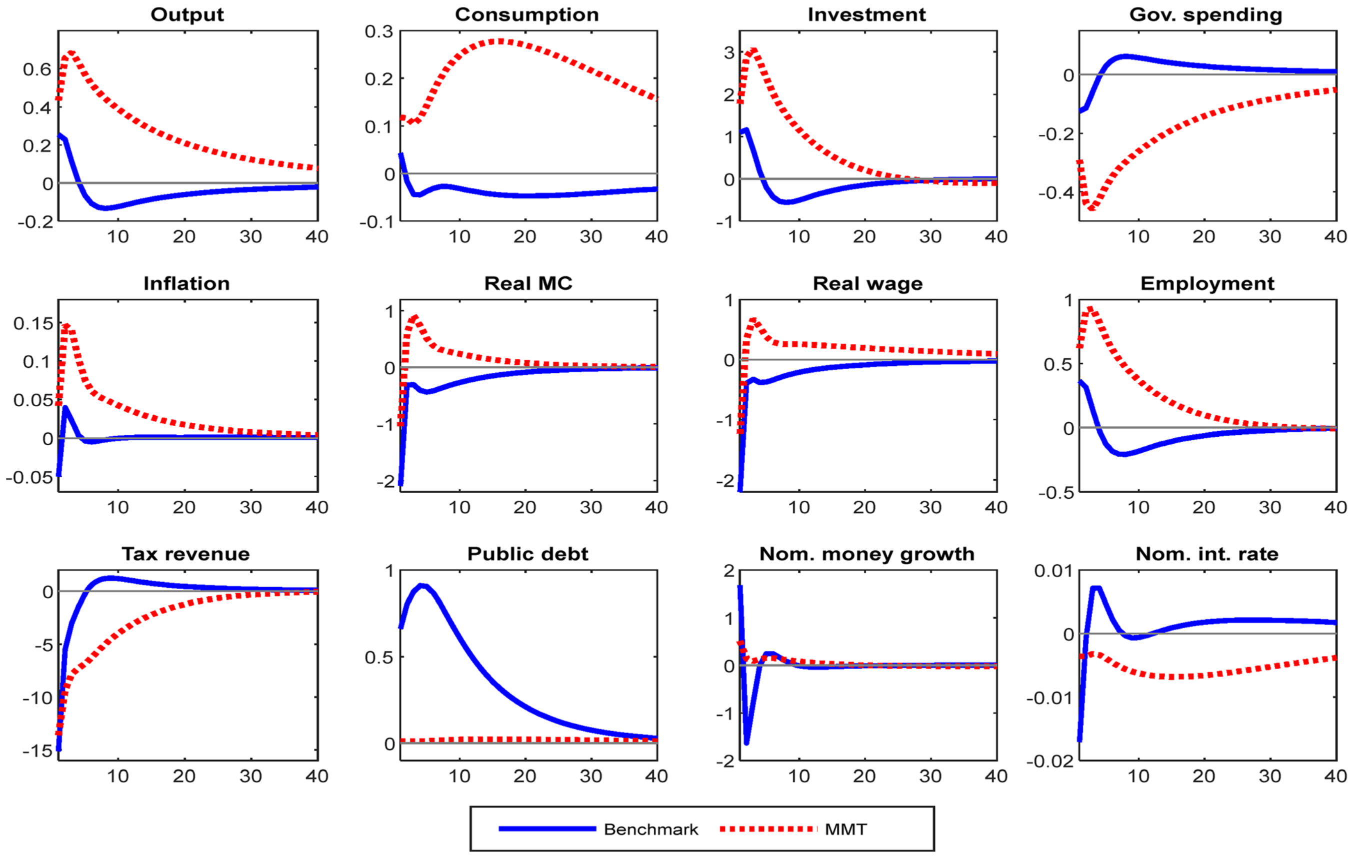

FIGURE 2 Effect of a tax cut on wages. [Colour figure can be viewed at wileyonlinelibrary.com]

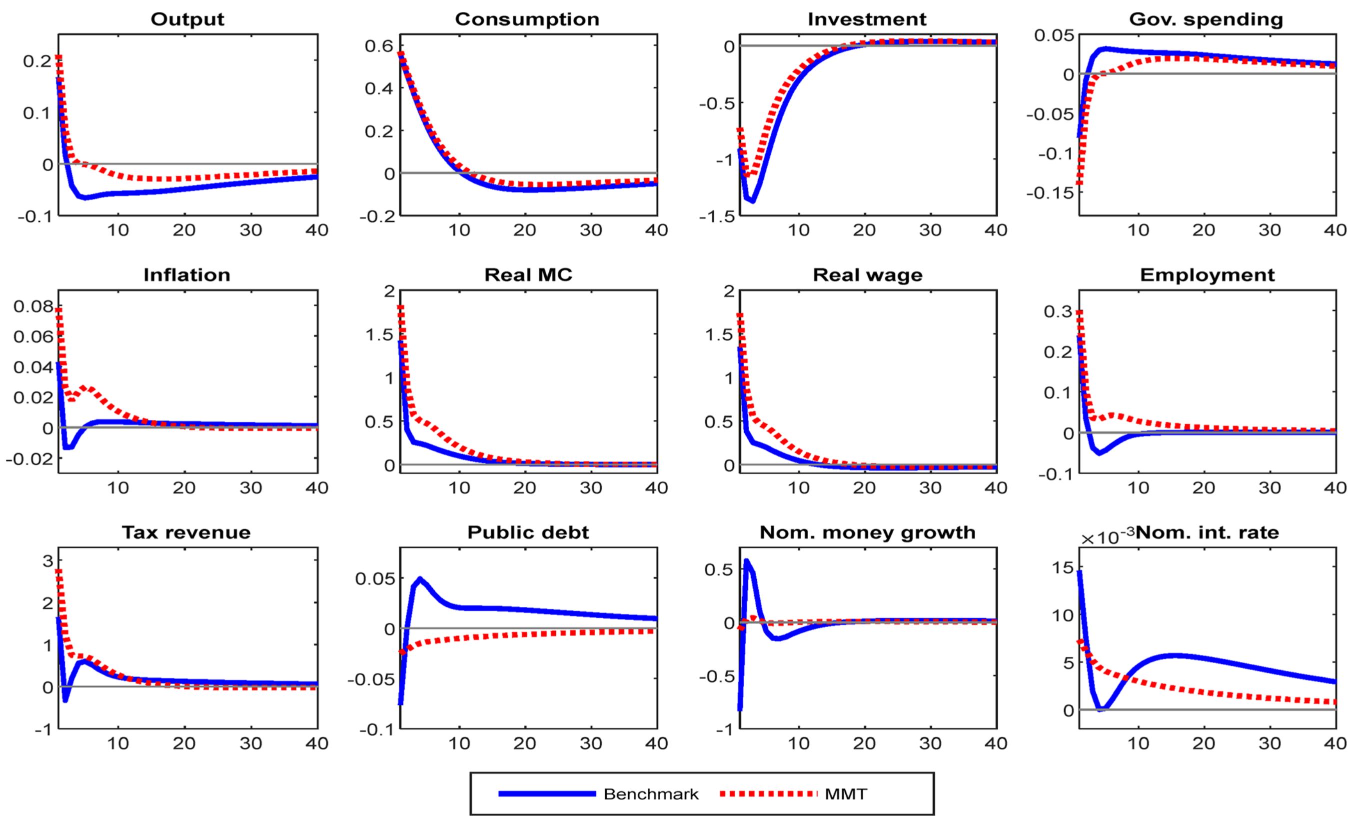

FIGURE 3 Effect of a rise in consumption. [Colour figure can be viewed at wileyonlinelibrary.com]

falls under both models to reduce the output gap, and the tax rate rises under the benchmark model to reduce the gap and under MMT to reduce inflation; one is monetary, where under the benchmark model the Taylor rule raises rates, while under MMT the rise in money demand raises rates less, with the money supply changing little with limited deficit changes. What we see here is that government spending and tax revenues differ little between the two models, suggesting that fiscal responses are similar. However, the interest rate responses differ sharply, being considerably larger under the benchmark model. This fits in with the picture of an MMT world in which money is largely accommodative to fiscal needs and to money demands triggered by output rises. It is only intolerant of demands triggered by inflation, because of the inflation target in the MMT tax function.

3 | CONFRONTING THE MODELS WITH THE DATA: CAN EITHER MODEL FIT THE FACTS?

We have seen that the different monetary policies asserted by the benchmark and MMT models imply quite different model behaviour, which will differentiate the models' capacity to match the data behaviour. In this section we evaluate this capacity. We do so by testing the models formally with a statistical test—the indirect inference Wald test, which compares the models' behaviour to the data's as characterized by an auxiliary, empirical model which can be viewed as a reduced form of the 'true' model. Indirect inference (II), which is a simulation-based method, was originally designed for estimating models whose likelihood functions were too complex for them to be estimated directly (Gourieroux et al., 1993; Gourieroux & Monfort, 1996; Gregory & Smith, 1991, 1993; Smith, 1993). The method has been developed more recently by Minford et al. (2008), Meenagh et al. (2009), Le et al. (2011, 2016) and Minford et al. (2019) to be a formal statistical test for DSGE models, which evaluates whether a candidate model—estimated or calibrated—can pass a Wald test on the distance between the model and the data with a high-enough probability such that the model may be considered 'true'. The p-value of the test may also be used for ranking competing models.

While the Bayesian method has been the workhorse for empirical DSGE analyses since Smets and Wouters (2007), we deviate from this convention by using indirect inference here since it is our aim to test, rather than just estimate, the models, which would enable us to determine if any of them is rejected by the data when their best-fitting version is evaluated. The Bayesian method, which estimates a model with set priors, does not generally test whether the model fits the data or not. The DSGE-VAR method of Del Negro and Schorfheide (2006), which is also a Bayesian method, does evaluate model fit; however it only does so informally, by estimating a hyper-parameter interpreted as a goodness-of-fit index, which is not a statistical test and therefore, provides no indication as to when a model should be rejected. The Maximum Likelihood method does test as well as estimating a model formally—like indirect inference; but ML estimates in small samples (which are common in macro-models including ours below) are highly biased—as is well known—and, as the Monte Carlo experiments of Le et al. (2016) show, likelihood tests generally suffer from insufficient power to reject a false model when it can be rejected by indirect inference tests with good power.

We elaborate the method of indirect inference in the following section.

3.1 | Estimating and testing a DSGE model with indirect inference

The basic idea is to use an unrestricted, empirical model, which is used as an auxiliary model, for features of the data (the 'facts') to be established; the DSGE model is then estimated/tested against such features based on the distance between the two models' implications. In model estimation where the DSGE parameters are unknown, the task is to find parameter values that minimize this distance. In model testing where the DSGE parameters are known in advance, the task is to judge whether such distance is sufficiently large (small), such that the DSGE model can (cannot) be rejected at a chosen significance level. The whole procedure may be described with the following three steps.

3.1.1 | Step 1: Construct descriptors of the data behaviour using the auxiliary model

Here we use an unrestricted VAR with a deterministic trend:

$$Y_t = C + A(L)Y_{t-1} + Bt + e_t, \qquad (23)$$

where Y_t is a vector of endogenous variables whose behaviour is what we want the DSGE model to fit, C is a vector of constants, t is the deterministic trend, e_t is a vector of the VAR residuals; A and B are matrices of the VAR coefficients. It is worth pointing that by fitting the data to (23), our purpose is not to find an empirical model that 'fits the data the best'. Instead, the empirical model, which is used as an auxiliary model here, is estimated for providing a benchmark description of the data against which the DSGE model can be evaluated. Any unrestricted model may in principle be used. Here we use a VAR, as the linear solution of any DSGE model can be written as a VAR with restrictions. Using an unrestricted VAR to describe the data therefore provides a natural benchmark which the DSGE model—if it was 'true'—has to match.

Since the debate on MMT revolves around the interaction between government spending, monetary policy, and output and inflation, we set $Y_t \equiv (g_t, R_t, y_t, \pi_t)'$. We use a $VAR(1)$, instead of higher-order VARs, in order to limit the degrees of freedom used in describing the data. Meenagh et al. (2019) show that raising the VAR order tends to raise the power of the test excessively, preventing tractable models close to the truth from passing the test. A VAR(1) has considerable but not such excessive power.

Descriptors of the data behaviour may be simply the VAR estimates or functions of them. Here, we let them be the VAR parameters and the variances of the VAR residuals, such that the data behaviour we require the DSGE model to fit is their dynamic behaviour (including cross-variable interactions) and volatility. These data descriptors are denoted as Φ^{Act}.

3.1.2 | Step 2: Simulate the DSGE model to create parallel simulations; and with each of these, re-estimate the auxiliary model to generate a distribution of the same data descriptors

In order to simulate the shocks implied by the DSGE model being tested, we first calculate the historical shocks implied by the model and the data. We then generate parallel simulations by bootstrapping these sample shocks. Effectively, the simulations are based on an estimate of the small sample distribution of the DSGE shocks, which Le et al. (2011) find to be generally more accurate than the asymptotic distribution for small samples.

The distribution of the data descriptors estimated from these parallel simulations, and so implied by the DSGE model, is denoted as $\Phi^{\text{Sim}} = \left(\Phi^{\text{Sim1}}, \Phi^{\text{Sim2}}, \dots, \Phi^{\text{SimN}}\right)$. In model estimation, we search for DSGE parameters which minimize the distance between Φ^{Act} and $\overline{\Phi}$, where $\overline{\Phi} = \mathrm{E}\left(\Phi^{\text{Sim}}\right)$. In model testing, we ask whether Φ^{Act} came from this distribution with a high-enough probability, that is, the distance between Φ^{Act} and $\overline{\Phi}$ is sufficiently close, such that the DSGE model is not rejected by the data.

3.1.3 | Step 3: Evaluate the distance between the data and the DSGE model

The distance between the data and the DSGE model, which is both the objective function in estimation and the test statistic in testing, is given by the Wald statistic:

$$Wald = \left(\Phi^{\text{Act}} - \overline{\Phi}\right)' \sum\nolimits_{\Phi\Phi}^{-1} \left(\Phi^{\text{Act}} - \overline{\Phi}\right), \tag{24}$$

where $\sum_{\Phi\Phi}$ is the variance–covariance matrix of the vector of the data descriptors generated with the parallel simulations.

To estimate the model, the II estimator conducts a grid search for the DSGE parameters until (24) is minimized.[10] The optimal set of parameters may be denoted as θ^{DSGE}.

To test whether the model is rejected with a given set of DSGE parameters (be it the optimal set or any other set), we set the null hypothesis that 'the DSGE model is true' (i.e., $\mathrm{H}_0 : \Phi = \overline{\Phi}$, where Φ is a vector of the hypothetical true values of the data descriptors), and we calculate the p-value of the null hypothesis using:

$$P = (100 - WP)/100, \tag{25}$$

where WP is the percentile of Φ^{Act} in the distribution of Φ^{Sim}. The DSGE model would pass (fail) the Wald test if the p-value is above (below) the $1\%, 5\%$ or 10% threshold.

3.2 | Data and calibrated parameters

The variables observed are: output, investment, government spending, public debt outstanding, the nominal interest rate, the money supply, inflation, the tax rate on wages, and the capital stock. These embrace the four variables fitted to (23) in Step 1 for generating the chosen data descriptors; and other 'state variables' used by the solution of the DSGE models for calculating the historical shocks in Step 2; the data are observed between 2008Q1 and 2019Q4. Both the nominal interest rate (which we measure with the corporate bond rate), inflation and the tax rate on wages are measured as quarterly rates. The other variables, defined in real and per-capita term, are measured in natural logarithm. The processed data are plotted in Figure 4. The data sources, the time series collected, and the adjustments to the raw data are detailed in the Appendix.

Of the model parameters, we fix those that are known to be hard to identify or for which consensus has been reached in the literature at their calibrated values, where

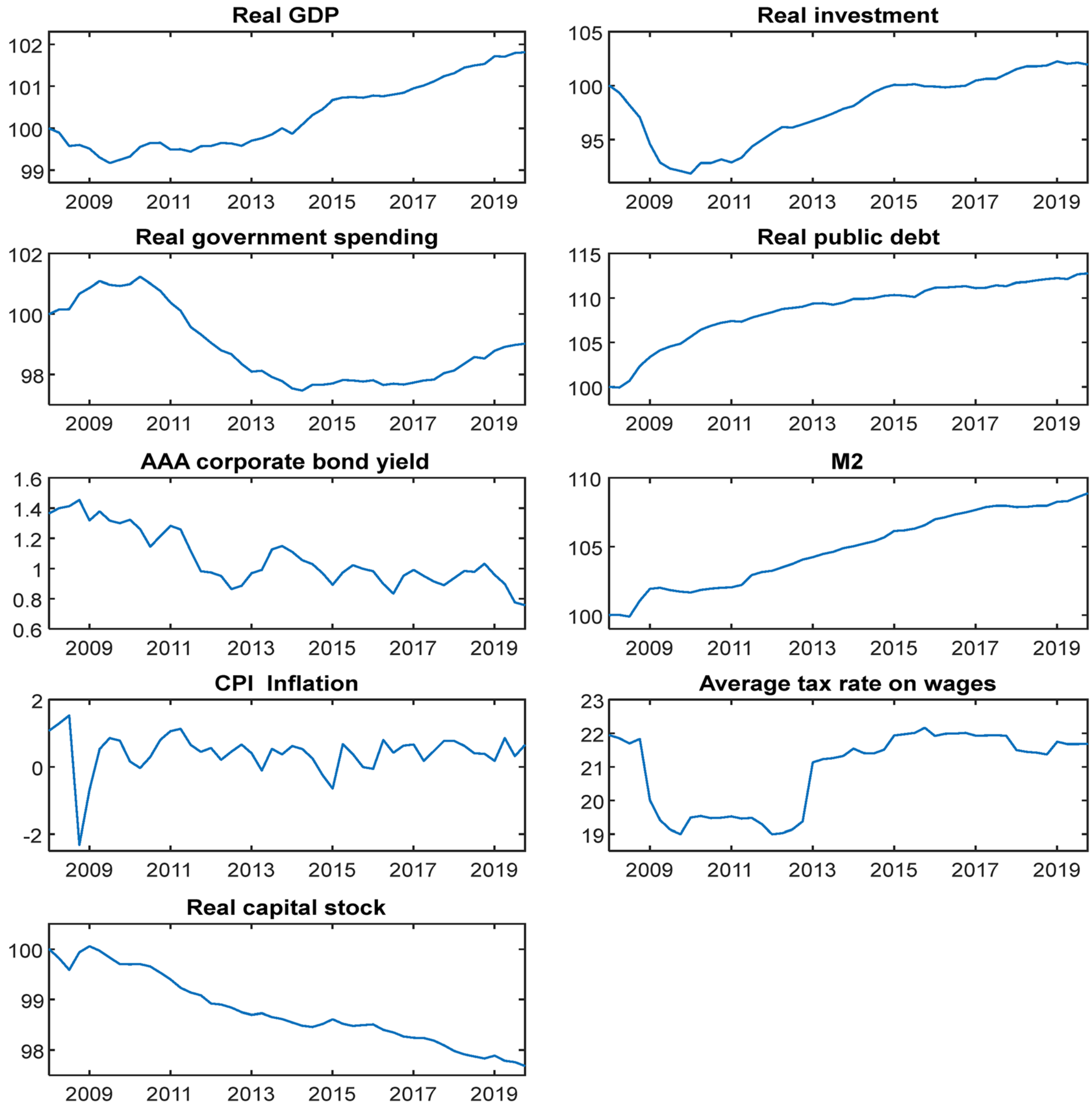

FIGURE 4 The data. [Colour figure can be viewed at wileyonlinelibrary.com]

we set $\beta = 0.995, u = 0.3, \delta = 0.025, \pi^* = 0.02$, $\overline{g} = 0.22$ and $\overline{\tau} = 0.21$. These values resemble those used by Smets and Wouters (2007) and Leeper et al. (2010), to which we also refer in setting the starting values for the estimated parameters reported in the following section.[12]

3.3 | Model estimates and fit

The estimated parameters and the models' *p*-values are reported in Table 1.

We can see that the II estimator finds quite different values of the structural parameters for the two models. Most notably, the benchmark model suggests literally no consumption habit (ϑ), but a high relative preference to leisure (ψ), while the opposite is found under MMT. The benchmark model also suggests little price indexation (ϵ), though both models agree on a high Calvo non-adjusting probability (ω). The difference in the other structural parameters, which is less striking, is also obvious. In terms of the policy parameters, the benchmark model suggests a high degree of interest rate smoothing (ρ_R) and an active interest rate response to inflation (φ_π), while the MMT model suggests an active tax rate response (ϕ_π). Government spending responds modestly, in both models, to output (γ_x). Debt is stabilized actively by the tax rate under the benchmark model (ϕ_b), but is adjusted actively under MMT to stabilize the nominal interest rate (ς). The shock processes suggested by the two models are, however, similar; in particular, they both agree on the high persistence of the time preference shock and government spending shock $\left(\rho_j \text{ and } \rho_g\right)$.

TABLE 1 Model parameters and p-values.

Parameter	Definition	Starting value	II estimate: Benchmark	II estimate: MMT
β	Time discount factor	0.995	Fixed at starting value	
u	Labour share	0.3	Fixed at starting value	
δ	Capital depreciation rate	0.025	Fixed at starting value	
π^*	Annual inflation target	0.02	Fixed at starting value	
$\bar{g}$	Steady-state government spending	0.218	Fixed at starting value	
$\bar{\tau}$	Steady-state tax rate on wage income	0.205	Fixed at starting value	
ϑ	Consumption habit persistence	0.5	0.01	0.53
η	Inverse of wage elasticity of labour	2	3.23	2.04
χ	Preference to money	0.003	0.05	0.01
ψ	Preference to leisure	1.5	2.05	0.94
ϵ	Inflation indexation	0.5	0.07	0.38
θ	Price elasticity of demand	7.5	14.9	13.8
ω	Calvo non-adjusting probability	0.83	0.75	0.92
F	Cost to capital adjustment	10	14.6	18.3
ρ_R	Interest rate smoothness	0.75	0.83	–
φ_π	Interest rate response to inflation	1.5	2.00	–
φ_x	Interest rate response to output	0.12	0.00	–
γ_x	Gov. spending response to output	−0.07	−0.49	−0.67
γ_b	Gov. spending response to debt	−0.4	0.00	–
ϕ_x	Tax rate response to output	0.5	0.07	–
ϕ_b	Tax rate response to debt	0.4	1.67	–
ϕ_π	Tax rate response to inflation	0.5	–	1.64
ς	Debt response to interest rate	−0.5	–	−1.39
ρ_j	Persistence of the time preference shock	0.5	0.82	0.89
ρ_z	Persistence of the productivity shock	0.5	0.35	0.21
ρ_π	Persistence of the mark-up shock	0.5	0.35	0.17
ρ_i	Persistence of the investment shock	0.5	0.77	0.84
ρ_g	Persistence of the gov. spending shock	0.5	0.99	0.99
ρ_τ	Persistence of the tax policy shock	0.5	0.90	0.45
ρ_{TR}	Persistence of the Taylor rule shock	0.5	0.15	–
ρ_b	Persistence of the debt supply shock	0.5	–	0.83
Model p-value (H_0: the DSGE model is true)		Benchmark: 58.3%	MMT: 2.70%	

Note: Sample: 2008Q1–2019Q4. Variables accounted by the auxiliary VAR model: g_t, R_t, y_t, π_t.

How do the models fit the data? According to the reported p-values, i.e., 58% for the benchmark model and 2.7% for the MMT model, the benchmark model passes the Wald test at the usual 5% significance level comfortably, whereas the MMT model is clearly rejected. Given the null hypothesis of the test that 'the DSGE model is true', this result therefore suggests that—while the MMT model is highly unlikely to have generated the observed data (viz. g_t, R_t, y_t, π_t, whose joint behaviour is characterized by the unrestricted VAR(1) chosen to describe the facts)—the benchmark model is quite 'probable'. Thus from a statistical viewpoint the benchmark model is highly significant, whereas the MMT model is insignificant. Thus MMT does not appear to be a valid explanation of how fiscal and monetary policies have interacted and affected the US economy since the Financial Crisis, let alone '*for the past 4000 years*' as Wray (2019) would have hoped. Instead, the fact that the benchmark model, which assumes a Taylor rule and Ricardian fiscal policies, has passed the test is strong evidence of monetary independence and fiscal policies being well disciplined, as understood and advocated by mainstream economists.

In the following sections, we use the benchmark model as informed by the above test as the 'true' model to analyse how output and inflation are affected by shocks since the Crisis—an episode which is much less studied in the literature, especially with a model surviving a formal statistical test like ours; and then go on to evaluate the welfare implications of a potential policy reform in the spirit of MMT.

4 | HOW DO SHOCKS AFFECT OUTPUT AND INFLATION POST-CRISIS?

The benchmark model has seven shocks: the time preference shock, the productivity shock, the mark-up shock (which includes exogenous cost shocks), the investment shock, the government spending shock, the tax policy shock, and the monetary policy (interest rate) shock. We start by establishing how these shocks contribute to output and inflation volatilities according to a forecast error variance decomposition. We then analyse the model's working with the impulse responses to the key shocks. We then consider how output and inflation were driven by these shocks in the post-Crisis history.

4.1 | Variance decomposition

Table 2 decomposes the variances of output and inflation on different forecast horizons.

As the results show, for both variables the shocks' contribution to the variables' variance does not change much as the forecast horizon progresses. This indicates a generally fast convergence of the determining shocks. Output is mainly affected by the productivity shock, which accounts for 48–54% of its variance; and the mark-up shock, which accounts for 40%–47%. Inflation is dominated by the productivity shock, which accounts for 41%–46%; but less influenced by the mark-up shock which accounts for 30%, while the interest rate shock has nearly the same impact.

These findings are broadly in line with what has been established in the literature for the pre-Crisis episode—for example, Smets and Wouters (2007) and Iacoviello and Neri (2010)—in that, the supply side generally dominates the determination of output and inflation. What is new, as we discover here for the post-Crisis episode, is that the demand side hardly plays any role. For a comparison, the government spending shock and investment shock are found to contribute by up to 35% and 23%, respectively, of the short-run output variation in SW, while IN find the investment shock contributes by about 8% in the long run. Another key difference between the pre-Crisis episode and the post-Crisis episode is that, while the monetary policy (interest rate) shock plays a substantial role in determining inflation after the Crisis, it only contributes by some 5% in the pre-Crisis episode as found by SW and IN.

This variance decomposition exercise therefore reveals changes in the determinants of output and inflation since the Financial Crisis, which is of policy note.

4.2 | The key impulse responses

Figure 5 shows how output and inflation respond to a one-standard-error realization of the key shocks identified above. These IRFs are completely standard, where a rise in productivity raises output, generating an excess supply which then causes inflation to fall; a rise in the price mark-up raises retail prices and hence inflation directly, reducing aggregate demand which then leads to

TABLE 2 Variance decomposition.

Qtrs. Ahead	Variables	Pref.	Prod.	Mark	Invest	G.Spn.	W.Tax	Interest
4	Output	0.2	54.0	40.2	1.0	0.0	0.4	4.1
	Inflation	0.3	41.2	30.0	1.5	0.0	0.4	26.7
12	Output	0.1	48.9	46.4	1.2	0.0	0.3	3.2
	Inflation	0.2	45.5	29.9	1.4	0.0	0.4	22.5
20	Output	0.2	47.7	47.2	1.2	0.0	0.6	3.1
	Inflation	0.2	45.6	30.1	1.4	0.0	0.4	22.2
40	Output	0.2	47.5	47.2	1.3	0.1	0.7	3.1
	Inflation	0.2	45.6	30.1	1.4	0.0	0.4	22.2

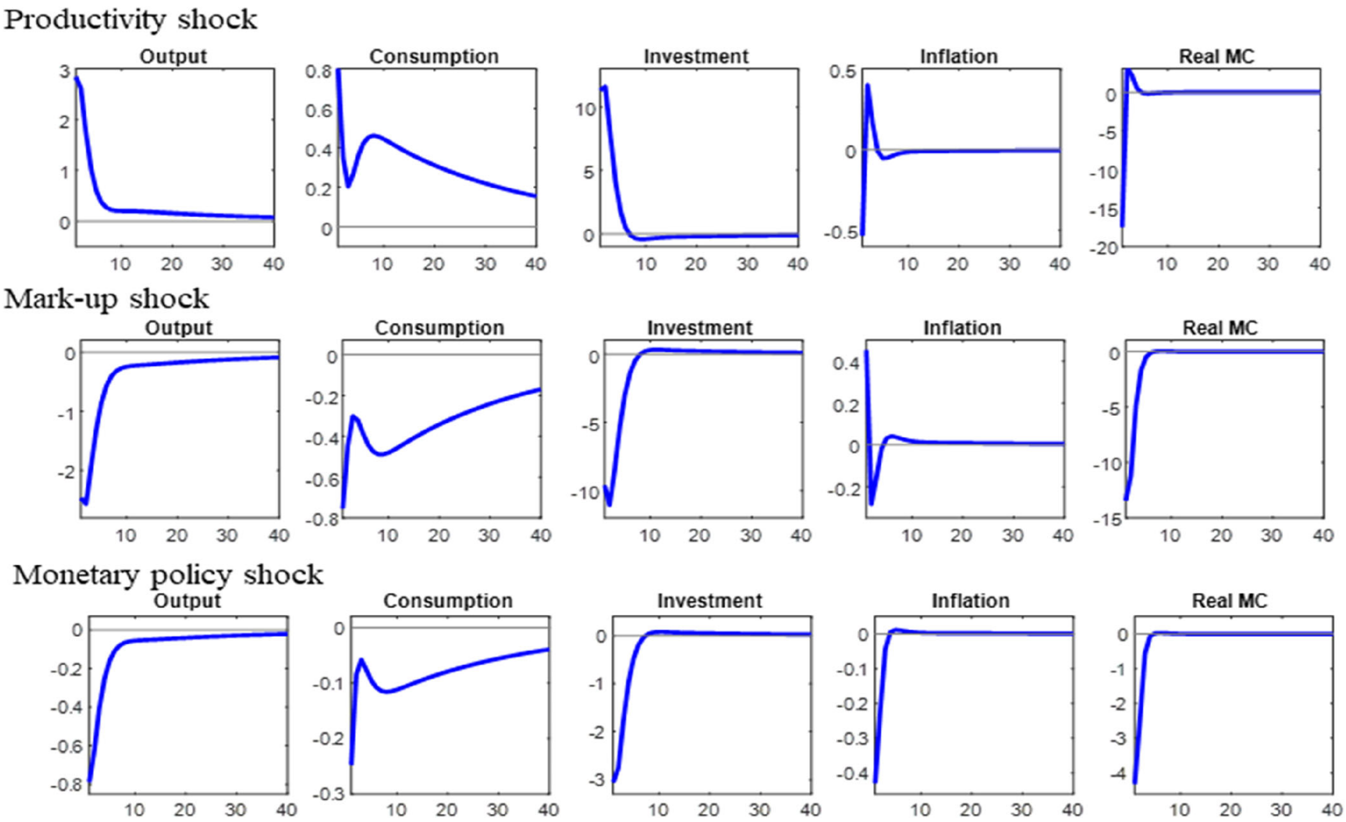

FIGURE 5 The key impulse responses. [Colour figure can be viewed at wileyonlinelibrary.com]

a fall in the equilibrium output; a rise in the nominal interest rate crowds out consumption and private investment, which reduces output and inflation in the usual manner as aggregate demand falls.

4.3 | Historical decomposition

The shocks realized over the sample according to the estimated model are reproduced in Figure 6. In Figure 7, we evaluate the impact of these shocks on the timelines of output and inflation over the sample history, which runs from the Financial Crisis, up to the outbreak of the COVID-19 pandemic.

As Figure 7 shows, the extended output recession since the Crisis up until 2015 was first induced by a surge in the price mark-up, deepened by tighter monetary conditions, and then maintained as productivity slumped while the former factors were improving (See also Figure 6 for the shocks' evolution). The productivity shock became more stabilized in the mid-2014, which established a weak momentum of recovery; and as it continued to improve, output recovered to the steady-state level in the mid-2015 and levelled out until Covid hit. Over the whole sample there was no real role of the fiscal shocks (which are embraced by the 'Others' factor in the Figure). The monetary policy shock only played a minor role.

Inflation was clearly less volatile and persistent than output. It was driven by the same set of shocks whose impacts were, however, quite balanced and generally offsetting. It was more destabilized around 2009 due to a slump caused by a drastic, but short-lived, surge in productivity and the nominal interest rate. Other than this exceptional period of time, it never deviated too much from the steady-state level.

4.4 | The impact of the COVID-19 pandemic and the Ukraine war

While the empirical analyses above have focused on the post-Financial Crisis episode until 2019, it would be interesting to know how our findings might be affected should the turbulent period of the COVID-19 pandemic and the Ukraine War be taken into consideration. Thus in this section we expand our sample for it to embrace these events; the extended sample spans from 2008Q1 to 2023Q2. We implement two exercises here: the first is to check whether the model ranking in fit we established in Section 3.3 is robust to this extended sample; the other is to extend our historical decomposition analysis in

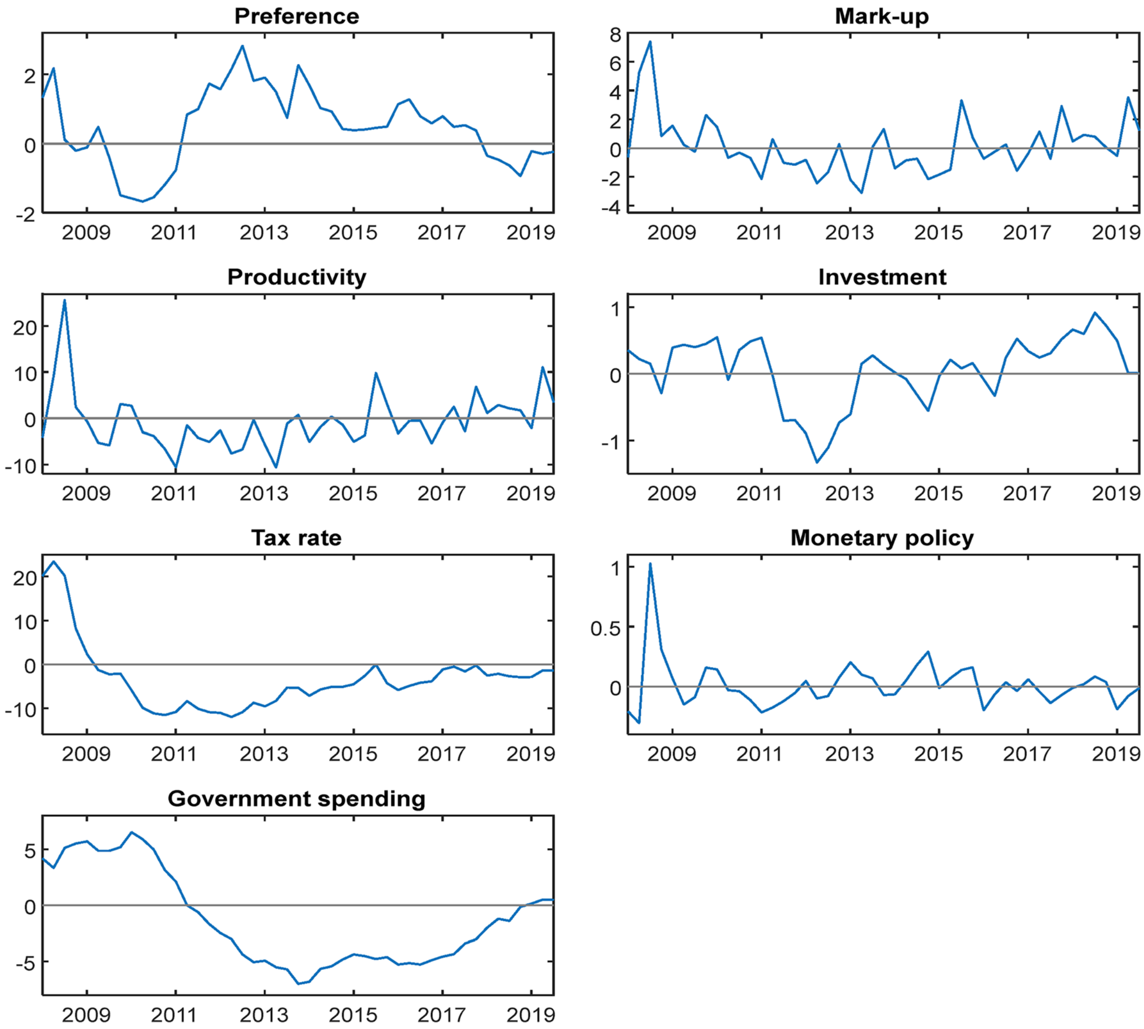

FIGURE 6 Historical shocks. [Colour figure can be viewed at wileyonlinelibrary.com]

Section 4.3 to include the Covid and War period to see how extreme shocks brought by these events have affected the timelines of output and inflation.

Table 3 reports the models' p-values when they are tested using the extended sample (for the same sets of parameters for each as reported in Table 1) and compares them to those found with the original sample. The addition of the COVID-and-War-period data makes both models less fit. But albeit this, the benchmark NK model still passes the Wald test comfortably with a p-value of 6.4%, which remains clearly above the 5% significance level. On the other hand, the MMT model is even more strongly rejected; in this case it has a p-value of only 0.4% which indicates that it can hardly fit. What this exercise tells us, therefore, is that our earlier finding that the benchmark NK model outperforms the MMT rival model and is the only model not rejected by the post-Financial Crisis data is robust to this choice of the extended sample which embraces the full range of crisis data in recent times, dominated as they are by sequential crises of various sorts including the COVID pandemic and the Ukraine War.

To see how these events have affected the timelines of output and inflation, we also extend our calculation of the historical shocks to cover the Covid and War period, which we show in contrast to the pre-Covid period in Figure 8. The Figure shows that the outbreak of the pandemic caused an immediate surge in consumption preference (likely due to 'panic buying'[13]), price mark-up (likely due to supply chain disruption), and productivity (as technologies and skills of the workforce both developed speedily); but a fall in investment. On the hand, market interest rates fell substantially as a result of QE, and so do tax rates as a result of various sorts of fiscal stimuli which also raised government spending. The shocks that hit the economy in this period were therefore quite distinct from those occurred in the pre-Covid episode both in their nature and in size.

Figure 9 shows how output and inflation were driven by these shocks in this turbulent period. As the

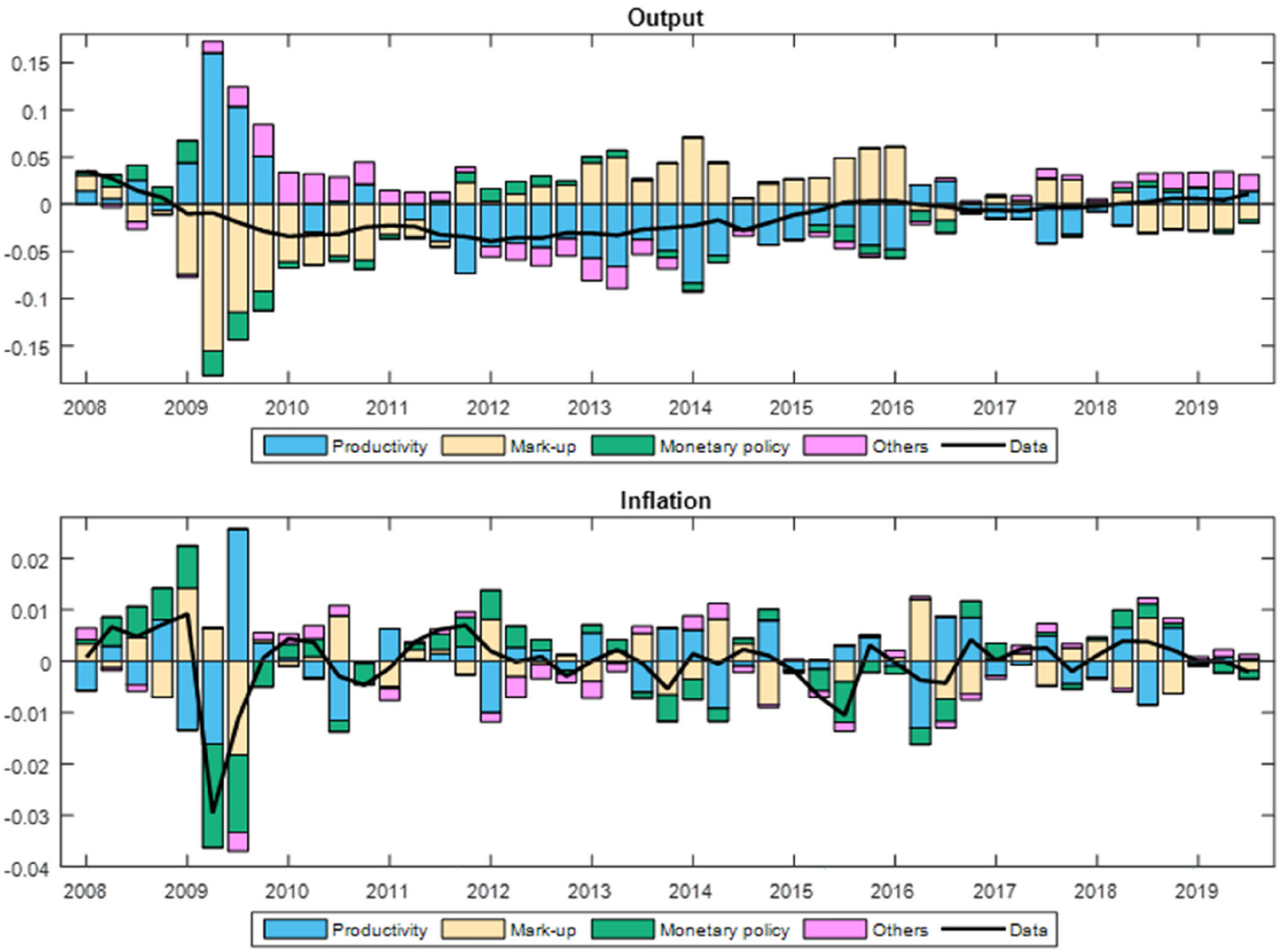

FIGURE 7 Historical decomposition. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 3 Model *p*-value with original and extended samples.

	p-Value	
Sample	**Benchmark**	**MMT**
2008Q1-2019Q4	58.3%	2.70%
2008Q1-2023Q2	6.40%	0.40%

Note: H_0, the DSGE model is true. Variables accounted by the auxiliary VAR model: g_t, R_t, y_t, π_t.

Figure shows, the output recession—the worst time found near the end of 2020—was caused by the severe supply-side disturbance embodied by the price mark-up shock which dominated the positive impact of the productivity shock. Monetary policy did not help much with the recovery during the pandemic, but its effect emerged gradually in supporting it thereafter albeit the persistent downward pressure. Inflation, on the other hand, was dominated by the monetary policy shock as the other shocks largely offset each other. The loose monetary conditions created by (the fourth round of) QE raised inflation to a historically high level since the Financial Crisis, which forms a sharp contrast to the pre-COVID episode when the earlier rounds of QE did not stimulate the economy much. Finally, despite the various sorts of fiscal stimuli since the outbreak of COVID, they are proven rather ineffective as they have been so since the Financial Crisis.

5 | EVALUATING THE WELFARE EFFECTS OF MMT AS A POLICY REGIME

So far, we have established that MMT fails to provide a valid explanation of the working of the US fiscal and monetary policies since the Financial Crisis. But looking forward—especially, given that policies under the current regime do not seem to be as effective in stimulating the real economy, could a shift of policies to an MMT basis, which embeds automatic deficit monetisation and taxing

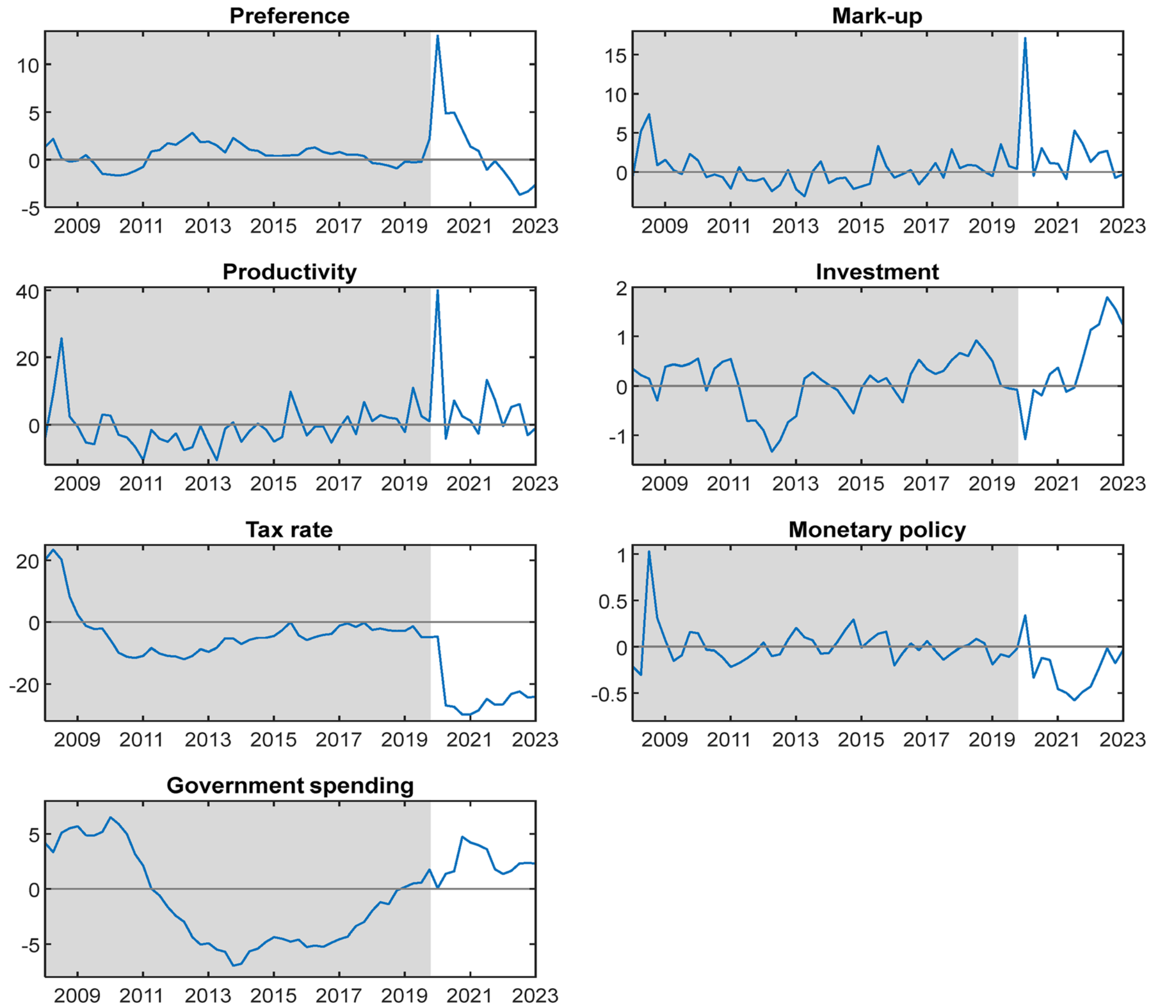

FIGURE 8 Historical shocks during the COVID and War period. [Colour figure can be viewed at wileyonlinelibrary.com]

as a means to stabilize inflation, be a promising way forward?

In this section we evaluate the potential gains/losses in terms of stability and welfare implied by MMT by comparing them to the implications of the benchmark model. We do so by simulating the models, by bootstrapping the historical shocks treated as a sample from the shocks' true distribution.[14] For each model we generate 20,000 independent bootstraps having the same length as the data sample; and calculate from them the average variances of the key variables, social welfare losses, and losses in household utility converted to equivalent permanent consumption.

For a better contrast we list the policy equations under each of the two regimes in Table 4. Under the benchmark Taylor-rule regime, monetary and fiscal policies are independent; nominal interest rate and money supply (implicitly) are governed by the Taylor rule targeting output and inflation, while government spending and the tax rate are governed by the fiscal rules targeting output and debt. Under MMT the money supply is adjusted as required by its various fiscal rules: money supply is created to finance government spending directly, while the latter in turn reacts to the output gap; the tax rate reduces the money supply in response to an inflation target; sales of debt, reducing money supply, are made in response to a nominal interest rate target. Notice that fiscal policy is active under both regimes in the sense that it responds to the output gap.

What do these alterations in the monetary and fiscal regime due to MMT achieve?

Table 5 reports the average variances of the simulated output, inflation and real interest rate under the two regimes. We find that the output variance under the current benchmark regime (which is only 2.08) rises by about 2.5 times (to 5.17) under the MMT regime, while the inflation and real interest rate variances are literally unaffected. Hence MMT policies would destabilize the real sector substantially while offering no gain (or even just compensation) in nominal or financial stability.

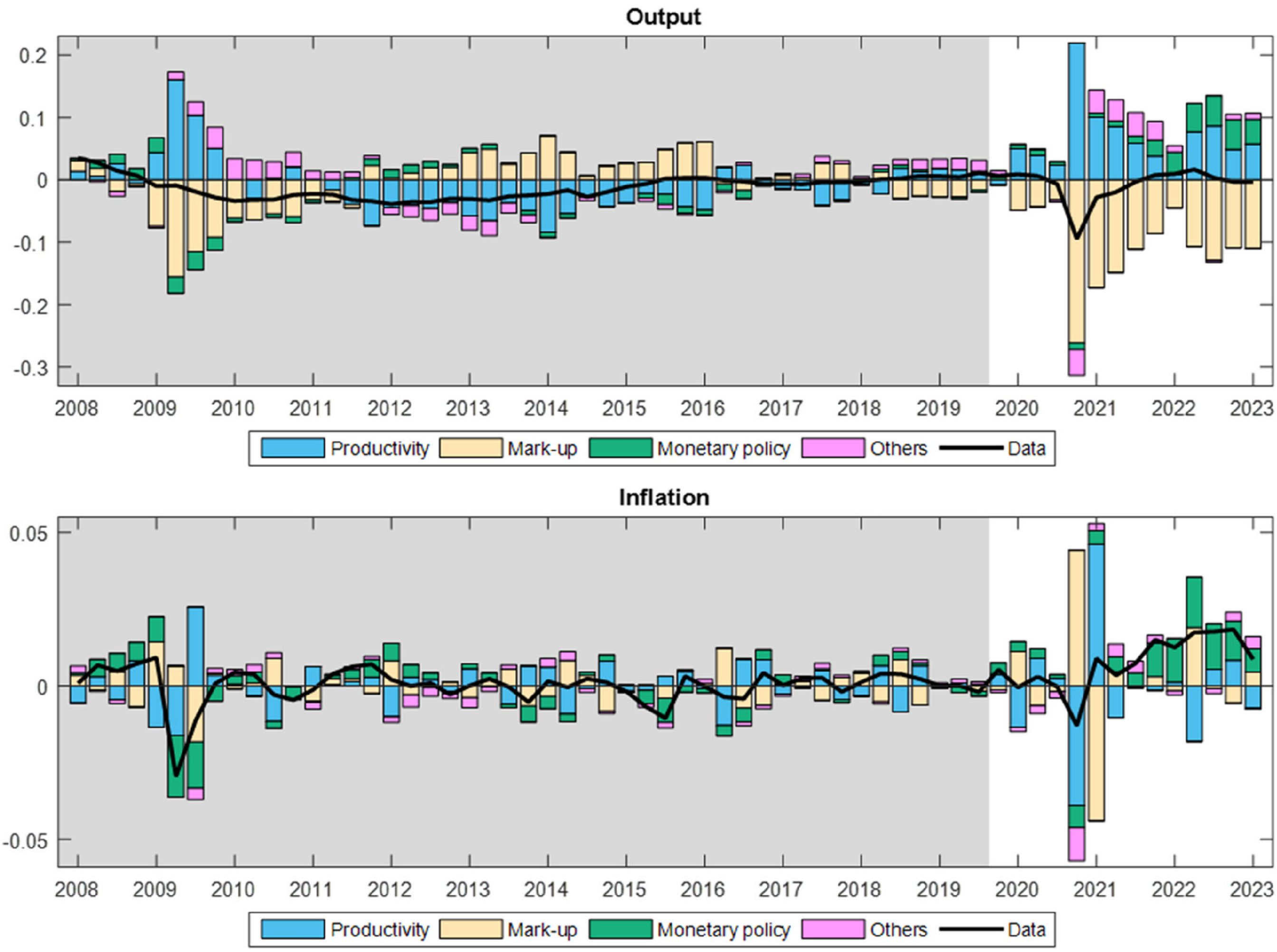

FIGURE 9 Historical decomposition during the COVID and War period. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 4 Policy equations under the benchmark Taylor and MMT regimes.

	Benchmark	MMT
Monetary policy	$1+R_t=(1+R_{t-1})^{\rho_R}\left(\frac{1+\pi_t}{1+\pi^*}\right)^{(1-\rho_R)\varphi_\pi} \cdot\left(\frac{y_t}{\bar{y}}\right)^{(1-\rho_R)\varphi_x}(1+\bar{R})^{(1-\rho_R)}\varepsilon_{TR,t}$	$h_t=g_t-t_t-\Delta b_t+r_{t-1}b_{t-1}$
Gov. Spending	$g_t=\varepsilon_{g,t}\,\bar{g}\left(\frac{y_t}{\bar{y}}\right)^{\gamma_x}\left(\frac{b_{t-1}}{\bar{b}}\right)^{\gamma_b}$	$g_t=\varepsilon_{g,t}\bar{g}\left(\frac{y_t}{\bar{y}}\right)^{\gamma_x}$
Tax policy	$(1+\tau_t)=\varepsilon_{\tau,t}(1+\bar{\tau})\left(\frac{y_t}{\bar{y}}\right)^{\phi_x}\left(\frac{b_{t-1}}{\bar{b}}\right)^{\phi_b}$	$1+\tau_t=\varepsilon_{\tau,t}(1+\bar{\tau})\left(\frac{1+\pi_t}{1+\pi^*}\right)^{\phi_\pi}$
Issuing of debts	$g_t-t_t=\Delta b_t-r_{t-1}b_{t-1}$	$b_t=\varepsilon_{b,t}\bar{b}\left(\frac{1+R_t}{1+\bar{R}}\right)^{\varsigma}$

TABLE 5 Variances of output, inflation and the real interest rate.

	$Var(\hat{y})$	$Var(\tilde{\pi})$	$Var(\tilde{r})$
Benchmark	2.08	0.35	0.11
MMT	5.17	0.34	0.13

Table 6 translates these changes into loss in household welfare in the spirit of Lucas (1987), which measures how much permanent consumption a representative agent would lose if he/she moves from one regime to another.[15] It turns out that MMT lowers the equivalent permanent consumption per capita by 0.8%

TABLE 6 Welfare losses by shifting from the benchmark regime to MMT.

Panel A: Loss in permanent consumption					
Lucas (1987)'s λ		0.83%			
Equiv. loss in cons		\$1795 per capita, per annum			
Panel B: loss in overall stability ($SWL = \frac{1}{2}\tilde{\pi}_t^2 + \varpi_y \hat{y}_t^2 + \varpi_r \tilde{r}_t^2$)					
	$\varpi_y \setminus \varpi_r$	0	0.1	0.3	0.5
Benchmark	0.1	0.28	0.29	0.30	0.31
MMT		0.43	0.44	0.45	0.46
Benchmark	0.3	0.48	0.49	0.50	0.52
MMT		0.95	0.95	0.97	0.98
Benchmark	0.5	0.70	0.70	0.71	0.72
MMT		1.46	1.47	1.48	0.50

(the 'Lucas λ'), which is worth \$1795 per annum with reference to the mean consumption level over the sample period and CPI in 2021. And this lowering is confirmed by ad hoc loss measures weighting the variances in different ways, which show that the overall stability loss under MMT is some 50%–110% higher.

Thus, plainly the MMT regime is inferior to the current Taylor-rule regime in stabilizing output and so consumption. The current regime embodies a fiscal response to output from both spending and taxes, only moderated by a Ricardian debt response. However, as we saw above when considering the model IRFs to a pure demand shock to output (where we let it be caused by a shift in the consumption preference), fiscal responses across the two models were very similar. On the other hand, the monetary policy response to the same shock via the interest rate channel is much weaker under MMT, as MMT is generally accommodative of money demands from output and fiscal changes, though it is not accommodative of money demands due to inflation. Hence, it would seem that the greater output volatility under MMT comes from its accommodative response to output shocks, while the similar inflation variance comes from its similar inflation response, which is non-accommodative, much like the Taylor rule.

6 | CONCLUSION

Modern Monetary Theory (MMT) portrays a world in which fiscal activism need not be constrained by the government budget, for which it has received much attention since the Financial Crisis while the space for monetary policy has largely contracted. Nevertheless, while MMT economists have failed to sell their Theory as well as its associated policy advice with evidence established by formal economic models, the wider group of mainstream economists have not been able to assess MMT in a formal manner, either—the fundamental barrier being that none has been able to embody MMT in a structural model in a testable form.

In this paper, we filled this gap by spelling out MMT as a full DSGE model, and tested its empirical validity and implications on economic stability and welfare, side by side with a standard New Keynesian (NK) model treated as the benchmark model. By testing both models against the post-Crisis data with indirect inference, we found the MMT model was rejected at the usual 5% significance level, while the NK model passed the test with a high probability. Thus, there is strong evidence against the MMT narrative of how fiscal and monetary policies have interacted and affected the US economy post-Crisis; by contrast, the NK model with a Taylor rule explains the data fairly well. It follows that the several rounds of QE in this episode should not be misinterpreted as an act of deficit monetisation; rather, they were what was required for the Fed to achieve its interest rate targets set in independence of the fiscal policy—which has been well disciplined—by the Taylor rule. We further found, by stochastic simulations of the two models, that if MMT and its version of fiscal policy had replaced the Taylor rule, it would have resulted in a material loss of welfare as MMT policies fail to stabilize output (and therefore consumption) in an active manner.

What we have established in this paper therefore suggests that MMT can neither explain the facts nor point the way forward for viable policy reforms.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data support the findings of this study are openly available in: 1. The Bureau of Economic Analysis, the US Department of Commerce; https://www.bea.gov/ 2. Federal Reserve Economic Data, Federal Reserve Bank of St. Louis, https://fred.stlouisfed.org/.

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ENDNOTES

[1] MMT economists do not deny money's role as a medium of exchange. Nevertheless, they argue that this role only comes after a currency has been chosen by the government to be the legitimate unit of account for tax payments. See Wray (1998) for example.

[2] New Keynesian models do not generally include money explicitly; nevertheless, it is assumed that in them there is an implicit demand for money, and that money supply is set by an interest rate-setting rule to equal money demand at the market interest rate.

[3] We focus on the post-Crisis episode only because (a) it is this episode that most advocates of MMT claim their Theory would fit, (b) debates over MMT policy advice are mainly concerned with recovery issues post-Crisis and, (c) it has been well established that the Fed's monetary policy behaviour before the Crisis is well described by the Taylor rule.

[4] An alternative method, as pointed out by one of our referees, is to use shadow interest rates when the risk-free rate hits the ZLB. However, recent studies have found that these estimates of shadow rates are generally quite sensitive to a number of factors; for example, Krippner (2013, 2015) finds they are sensitive to both the estimation method, maturity span, and the number of predictors chosen; Christensen and Rudebusch (2015) and Bauer and Rudebusch (2016) find they are sensitive to the threshold rate chosen to define the ZLB; Alfaro and Piña (2023) find they are also sensitive to certain data properties including the sample size and data smoothness.

[5] This is set to $\Gamma \equiv \frac{1-\vartheta}{(1-\vartheta\beta)}$, such that in the steady state $U_c' = 1/\bar{c}$, where $\bar{c}$ is the steady-state level of consumption.

[6] $V_{0,t} \equiv \lambda_t/\lambda_0$ is the marginal rate of substitution between incomes received in periods t and 0, where $\lambda_{i=0,t}$ is the Lagrangian multipliers in the household problem.

[7] One implicit assumption (which is barely mentioned by MMT economists, however) is that this must be before the tax rate has reached an upper limit defined by the Laffer curve. Going beyond such a limit higher tax rates would undermine tax revenue, so that excess money would have to generate a sufficient inflation tax—of potentially huge size—for the long-run government budget to be solvent. In our modelling here we respect this assumption by ensuring that the steady-state tax rate is below the Laffer curve limit such that the MMT model does not deliver such an 'unpleasant' outcome.

[8] To derive this condition, note that in the steady state where the net change in real debt outstanding is zero (19) reduces to $\bar{h} = \bar{g} - \bar{t} + \bar{r}\bar{b}$. Solving for $\bar{b}$ by rearranging this steady-state equation and substituting out h using (18) therefore yields $\bar{b} \approx \frac{1}{\bar{r}}\left(\bar{t} - \bar{g} + \overline{m}\frac{\bar{\pi}}{1+\bar{\pi}}\right)$.

[9] In this case, tax revenue rises both because the higher output raises employment—as under the benchmark model, and because the tax rate on wages rises in response to inflation under MMT.

[10] In our practice below we implement this search by using the Simulated Annealing algorithm.

[11] These parameters are calibrated for the models to imply key steady-state ratios that are broadly in line with the data according to a long-run, 'full' sample between 1966 and 2019. $\bar{g}$is set to 0.22 such that both models imply a government-spending-to-output ratio of about 12%. $\bar{\tau}$ is set to equal the sample mean of the tax rate on wage income.

[12] Note, however, that the starting values (which we report alongside the final estimated values in the following section for reference purposes) do not generally affect the estimation since the II estimator conducts a grid search for values permitted by the model theory assuming a uniform distribution.

[13] See Wang and Hao (2020) for example.

[14] In order that the simulations will have fully, but not overly, reflected the regimes' differences, we impose that the two models share the same 'deep' parameter values as found with the benchmark, 'true', model; for the small set of parameters that are MMT-specific, we use their sample estimates as reported in Table 1. The same principle applies to the choice of the 'historical sample shocks' bootstrapped for generating the simulations.

[15] The loss is calculated as $\lambda = exp\left[(1-\beta)\left(U^{MMT} - U^{Bench}\right)\right]$, where U^{Bench} and U^{MMT} are the household life-time utilities under the benchmark and MMT regimes, respectively.

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APPENDIX A: Model and the optimisation problems

A.1 | The benchmark model

A.1.1. | The household problem

Households maximize lifetime utility:

$$U_0 = E_0 \sum_{t=0}^{\infty} \beta^t j_t \left\{ \Gamma ln(c_t - \vartheta c_{t-1}) + \chi ln m_t - \psi \frac{n_t^{1+\eta}}{1+\eta} \right\}, \tag{A1}$$

by choosing c_t, n_t, m_t, k_t and s_t, subject to budget constraint:

$$\begin{aligned} c_t + s_t + m_t + q_t k_t = {} & (1-\tau_t) w_t n_t + (1+r_{t-1}) s_{t-1} + \frac{m_{t-1}}{1+\pi_t} \\ & + tr_t + r_{k,t} k_{t-1} + q_t (1-\delta) k_{t-1} \\ & + \Pi_{y,t} + \Pi_{k,t}, \end{aligned} \tag{A2}$$

The first order conditions are:

$$\frac{\partial U_0}{\partial c_t} : \Gamma \frac{1}{c_t - \vartheta c_{t-1}} - \beta E_t \left(\frac{j_{t+1}}{j_t} \right) \Gamma \vartheta \frac{1}{E_t c_{t+1} - \vartheta c_t} = \lambda_t, \tag{A3}$$

$$\frac{\partial U_0}{\partial n_t} : \psi n_t^{\eta} = \lambda_t (1-\tau_t) w_t, \tag{A4}$$

$$\frac{\partial U_0}{\partial m_t} : \left(\frac{\chi}{m_t} - \lambda_t \right) = -\beta E_t \left(\frac{j_{t+1}}{j_t} \right) E_t \lambda_{t+1} \frac{1}{(1+E_t \pi_{t+1})}, \tag{A5}$$

$$\frac{\partial U_0}{\partial k_t} : q_t = \beta E_t \left(\frac{j_{t+1}}{j_t} \right) E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \right) \left[E_t r_{k,t+1} + E_t q_{t+1} (1-\delta) \right], \tag{A6}$$

$$\frac{\partial U_0}{\partial s_t}:\lambda_t=\beta E_t\left(\frac{j_{t+1}}{j_t}\right)E_t\lambda_{t+1}(1+r_t), \tag{A7}$$

A.1.2. | The firms' problem

Individual firm j in a monopolistically competitive market maximizes:

$$\Pi_{y,0}=E_t\sum_{i=0}^{\infty}\omega^i\beta^iV_{i,t+i}\left(\frac{p_{jt}}{E_tP_{t+i}}-\varphi_{t+i}\right)y_{j,t+i}, \tag{A8}$$

by choosing p_{jt}, subject to the demand function $y_{j,t+i}=\left(\frac{p_{jt}}{P_t}\right)^{-\theta}y_t$. The first order condition is:

$$\widehat{p}_{jt}=(1-\omega\beta)\sum_{i=0}^{\infty}\omega^i\beta^i\left(E_t\widehat{\varphi}_{t+i}+E_t\widehat{P}_{t+i}\right), \tag{A9}$$

which, under Calvo (1983) pricing allowing for past inflation indexation, implies the hybrid Phillips curve:

$$\pi_t=\frac{1-\beta\Omega(1-\epsilon)-\epsilon}{1+\beta\epsilon\Omega}\overline{\pi}+\frac{\beta\Omega}{1+\beta\epsilon\Omega}E_t\pi_{t+1}+\frac{\epsilon}{1+\beta\epsilon\Omega}\pi_{t-1}+\frac{(1-\omega)(1-\omega\beta\Omega)}{\omega(1+\beta\epsilon\Omega)}\widehat{mc}_t+\widehat{\varepsilon}_{\pi,t}, \tag{A10}$$

Let the production function be:

$$y_t=z_tn_t^{1-u}(k_{t-1})^u, \tag{A11}$$

The optimal substitution between labour and capital is:

$$n_t=\frac{1-u}{u}\frac{r_{k,t}k_{t-1}}{w_t}, \tag{A12}$$

The real marginal cost of production is:

$$mc_t=\frac{1}{z_t}\left(\frac{1}{u}\right)^u\left(\frac{1}{1-u}\right)^{1-u}w_t^{1-u}r_{k,t}^u, \tag{A13}$$

Firm profit transferred to households in each period is:

$$\Pi_{y,t}=(1-mc_t)y_t, \tag{A14}$$

A.1.3. | The capital producer problem

Capital accumulates with the following rule:

$$k_t-k_{t-1}=\varepsilon_{i,t}(i_t-adj_t)-\delta k_{t-1}, \tag{A15}$$

subject to adjustment costs:

$$adj_t=\frac{F}{2}\left(\frac{i_t}{i_{t-1}}-1\right)^2 i_t, \tag{A16}$$

Capital producers maximize lifetime profit:

$$\Pi_{k,0}=E_0\sum_{t=0}^{\infty}\beta^tV_{0,t}[q_tk_t-q_t(1-\delta)k_{t-1}-i_t], \tag{A17}$$

by choosing i_t. The first order condition is:

$$\frac{\partial\Pi_{k,0}}{\partial i_t}:q_t\varepsilon_{i,t}\left[1-F\left(\frac{i_t}{i_{t-1}}-1\right)\frac{i_t}{i_{t-1}}-\frac{F}{2}\left(\frac{i_t}{i_{t-1}}-1\right)^2\right],$$
$$=1-\beta E_t\left(\frac{\lambda_{t+1}}{\lambda_t}\right)\left\{q_tE_t\varepsilon_{i,t+1}\left[F\left(\frac{i_{t+1}}{i_t}-1\right)\left(\frac{i_{t+1}}{i_t}\right)^2\right]\right\}, \tag{A18}$$

Capital producer profit transferred to households in each period is:

$$\Pi_{k,t}=q_tk_t-q_t(1-\delta)k_{t-1}-i_t, \tag{A19}$$

A.1.4. | Monetary policy

Taylor rule:

$$1+R_t=(1+R_{t-1})^{\rho_R}\left(\frac{1+\pi_t}{1+\pi^*}\right)^{(1-\rho_R)\varphi_\pi}\left(\frac{y_t}{\overline{y}}\right)^{(1-\rho_R)\varphi_x}\left(1+\overline{R}\right)^{(1-\rho_R)}\varepsilon_{TR,t}, \tag{A20}$$

Central bank balance sheet constraint:

$$m_t=\frac{m_{t-1}}{1+\pi_t}+h_t, \tag{A21}$$

A.1.5. | Fiscal policy

Government spending:

$$g_t = \varepsilon_{g,t}\bar{g}\left(\frac{y_t}{\bar{y}}\right)^{\gamma_x}\left(\frac{b_{t-1}}{\bar{b}}\right)^{\gamma_b}, \tag{A22}$$

where $\gamma_x, \gamma_b < 0$.

Tax policy:

$$(1+\tau_t) = \varepsilon_{\tau,t}(1+\bar{\tau})\left(\frac{y_t}{\bar{y}}\right)^{\phi_x}\left(\frac{b_{t-1}}{\bar{b}}\right)^{\phi_b}, \tag{A23}$$

where $\phi_x, \phi_b > 0$.

Tax revenue:

$$t_t = \tau_t w_t n, \tag{A24}$$

Government budget constraint:

$$g_t - t_t = \Delta b_t - r_{t-1}b_{t-1} + h_t - tr_t, \tag{A25}$$

where $h_t = tr_t$.

A.1.6. | Marking clearing and identities

Goods market clearing:

$$c_t + i_t + g_t = y_t, \tag{A26}$$

Fisher equation:

$$1 + R_t = (1+r_t)(1+E_t\pi_{t+1}), \tag{A27}$$

A.1.7. | Shock processes

The natural logarithm of all model shocks follow an AR (1) process.

A.2 | The MMT model variant

The MMT model is otherwise identical to the benchmark model except for the following modifications:

a. The change in real money supply is determined by the fiscal deficit (A new government budget constraint):

$$h_t = g_t - t_t - \Delta b_t + r_{t-1}b_{t-1}, \tag{A28}$$

b. The tax rate is adjusted to stabilize inflation (A new tax rule):

$$1 + \tau_t = \varepsilon_{\tau,t}(1+\bar{\tau})\left(\frac{1+\pi_t}{1+\pi^*}\right)^{\phi_\pi}, \tag{A29}$$

c. Public debt is adjusted to target the nominal interest rate (There is no longer a Taylor rule):

$$b_t = \varepsilon_{b,t}\bar{b}\left(\frac{1+R_t}{1+\bar{R}}\right)^{\varsigma}, \tag{A30}$$

d. Government spending targets output only (Public debt is no longer stabilized by the spending):

$$g_t = \varepsilon_{g,t}\bar{g}\left(\frac{y_t}{\bar{y}}\right)^{\gamma_x}, \tag{A31}$$

APPENDIX B: Data sources, time series collected, and adjustments to the raw data

The observable variables are: output, investment, government spending, public debt outstanding, nominal interest rate, money supply, inflation, tax rate on wages, and capital stock. The real variables are normalized by *CPI* and population; inflation is defined as the quarter-on-quarter growth of *CPI*; nominal interest rate is quoted as quarterly rate. All variables, except inflation, nominal interest rate and tax rate on wages, are in natural logarithm.

The sample spans from 2008Q1 to 2019Q4. Capital stock, which is only available as annual data at source, is collected from Feenstra et al. (2015) via the FRED database; the original time series is converted to quarterly data using the 'quadratic-match average' algorithm with *Eviews*®. The other time series are collected from FRED and the US Bureau of Economic Analysis. Seasonal adjustment is applied to all time series except nominal interest rate. Table B.1 details the time series collected, their sources, and the relevant adjustments.

TABLE B.1 Data sources, time series collected & adjustments to the raw data.

Obs. Variables	Time series collected	Source[a]	Divided by CPI?	Divided by pop?	Seasonally adjusted?
Output	'Nominal GDP'	BEA	√	√	√
Investment	'Fixed Private Investment'	BEA	√	√	√
Gov. Spending	'Gov. Cons. Expenditures & Gross Investment'	BEA	√	√	√
Debt outstanding	'Total Public Debt'	FRED	√	√	√
Nom. Interest rate	'AAA corporate bond yield'	FRED	N.A	N.A	N.A
Money supply	'M 2'	FRED	√	√	√
Inflation	'CPI' (Quarter-on-quarter growth)	FRED	N.A.	N.A.	√
Tax rate on wages[b]	'Personal current taxes' (IT)	BEA	N.A.	N.A.	N.A.
	'Wages and salaries' (W)	BEA	N.A.	N.A.	N.A.
	'Proprietors' income with IVA and CCAdj' (PRI)	BEA	N.A.	N.A.	N.A.
	'Rental income of persons with CCAdj' (RI)	BEA	N.A.	N.A.	N.A.
	'Corporate profits with IVA and CCAdj' (CP)	BEA	N.A.	N.A.	N.A.
	'Net interest and miscellaneous payments' (NIP)	BEA	N.A.	N.A.	N.A.
	'Contributions for gov. social insurance' (CSI)	BEA	N.A.	N.A.	N.A.
	'Compensation of employees' (EC)	BEA	N.A.	N.A.	N.A.
Capital stock	'Capital stock at current PPPs' (Feenstra et al., 2015)	FRED	√	√	√
Population index	'CNP16OV'	FRED	N.A.	N.A.	√

[a]BEA, US Bureau of Economic Analysis; FRED, Federal Reserve Economic Data.
[b]The rate is calculated following Leeper et al. (2010). $\tau = \frac{\tau^p(W+PRI/2)+CSI}{EC+PRI/2}$, where $\tau^p = \frac{IT}{W+PRI/2+CI}$, $CI = RI + CP + CSI$.