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Calculating government consumption multipliers in New Zealand using an estimated DSGE model

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Calculating Government Consumption Multipliers in New Zealand Using an Estimated DSGE Model

Andrew Binning

New Zealand Treasury Working Paper 24/01

April 2024

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Calculating Government Consumption Multipliers in New Zealand
Using an Estimated DSGE Model

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Abstract

Fiscal multipliers provide a way of quantifying the GDP gain for a given (discretionary) fiscal policy intervention. I compute government consumption multipliers for New Zealand, in normal times and when monetary policy is constrained at the effective lower bound, using an estimated monetary-fiscal dynamic stochastic general equilibrium model. Quantifying the impact of discretionary fiscal policy is important when considering the design of fiscal support packages to offset future economic downturns. I calculate multipliers under a number of different monetary policy assumptions when imposing the lower bound on interest rates. I investigate the range of results implied by the model and the features of the policy and economic environments that lead to larger government consumption multipliers. I find that estimated government consumption multipliers are larger when interest rates are at the lower bound, but still smaller than 1, when entry and exit to the lower bound are determined by both economic conditions and the central bank's reaction function. This implies increases in government consumption crowd out other expenditure. When the central bank can commit to holding interest rates fixed for 2 or more years, independent of economic conditions, government consumption multipliers can exceed 1. Factors that amplify demand shocks are more likely to increase multipliers, especially at the lower bound, though these features may be undesirable for macroeconomic stabilisation more generally. Larger government consumption multipliers are not an end in themselves, rather the size of the multipliers can influence the design of discretionary policy programmes.

JEL CLASSIFICATION

C11 Bayesian Analysis: General
E52 Monetary Policy
E62 Fiscal Policy
E63 Comparative or Joint Analysis of Fiscal and
Monetary Policy; Stabilization; Treasury Policy

KEYWORDS

Government consumption multipliers; monetary policy;
effective lower bound; prior predictive analysis; Monte Carlo
filtering

Executive Summary

Discretionary fiscal policy can play an important role in supporting economic activity during recessions. This is especially true in deep and prolonged recessions when the lower bound on interest rates is binding, and implementation lags become less problematic because stimulus is required for a longer period of time. Many developed countries, New Zealand included, delivered unprecedented fiscal support through the COVID pandemic as conventional monetary policy reached its limits. Understanding the impact of discretionary fiscal policy is key to designing and implementing fiscal policy in future recessions. The effectiveness of discretionary fiscal policy is typically measured by fiscal multipliers that measure the dollar change in GDP for a dollar change in government spending or tax revenue. In this paper I calculate government consumption multipliers for New Zealand using an estimated small open economy monetary-fiscal dynamic stochastic general equilibrium (DSGE) model.

Monetary policy is a key determinant of the size of *fiscal* multipliers. The degree to which monetary policy reacts to or accommodates a given fiscal shock determines the real interest rate's response, which affects private consumption, private investment, and GDP. The lower bound on nominal interest rates can constrain the monetary policy response to fiscal shocks during recessions, amplifying fiscal multipliers. With no consensus in the literature on how monetary policy should be specified when modelling the lower bound, I calculate government consumption multipliers in New Zealand under four different monetary policy settings. These include when monetary policy is set according to a Taylor-type rule in normal times, two different assumptions about how the shadow interest rate is set when monetary policy is constrained by the lower bound on nominal interest rates, and when interest rates are fixed or pegged for a set period of time. The shadow interest rate is the unobserved counterfactual interest rate that would be set in the absence of the lower bound, according to the central bank's interest rate rule, when the economy is at the lower bound. When the lower bound is endogenously binding (determined by economic conditions), the shadow interest rate determines entry and exit to the lower bound and how long it is expected to bind. The two shadow interest rate rules investigated differ in their assumptions about interest rate smoothing, which has implications for the length of time the economy spends at the lower bound, and how future monetary policy reacts to fiscal shocks that occur at the lower bound. The fixed or pegged interest rate proxies for calendar-based "Odyssean" forward guidance, where the central bank announces their commitment to deviate from their usual behaviour and keep interest rates fixed at the lower bound for a set time period, independent of economic conditions. It is not clear which assumption about monetary policy is the best representation of actual policy at the lower bound and which is best from a normative perspective.

I find government consumption multipliers are larger when monetary policy is constrained by the lower bound on interest rates, although they do not exceed 1. As GDP is the sum of private consumption, private investment, government consumption, government investment and net exports, government consumption multipliers smaller than 1 suggest increases in government consumption crowd out other expenditure. Government consumption multipliers are larger at the lower bound when the shadow interest rate is a function of the lagged actual interest rate. Under this shadow rate rule, future monetary policy does not respond directly to fiscal shocks that occur while the economy is at the lower bound. When the shadow interest rate is a function of the lagged shadow interest rate, future monetary policy responds to fiscal shocks at the lower bound, reducing the size of fiscal multipliers. Under this assumption, monetary policy responds to current and past deviations of inflation and output from target in the periods after the economy has exited the lower bound. Monetary policy that responds to current and historic economic

conditions has been shown to have good macroeconomic stabilisation properties in normal times, highlighting a potential trade-off between strengthening discretionary fiscal policy at the expense of stabilisation policy. Government consumption multipliers only exceed 1 when the central bank is able to commit to keeping interest rates fixed for at least 8 quarters.

I use parameter sensitivity analysis to (i) investigate the range of fiscal multipliers implied by both the model and prior beliefs about the model parameters and (ii) investigate which parameters and parameter regions are more likely to generate larger government consumption multipliers. Through a number of simulation exercises I confirm that many of the parameters and parameter regions that are more likely to generate larger government consumption multipliers are also associated with a more volatile economy. This indicates that fiscal multipliers are likely to be larger in economies with weaker stabilisation properties, and further highlights the tensions and trade-offs between enhancing discretionary fiscal policy at the expense of macroeconomic stabilisation policy. It is important to appreciate that large government consumption multipliers are a means to an end and not an end in themselves.

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Calculating Government Consumption Multipliers in New Zealand Using an Estimated DSGE Model

1. Introduction

Discretionary fiscal policy can play an important role in supporting economic activity during recessions. This is especially true in deep and prolonged recessions, when monetary policy is constrained by the effective lower bound (ELB) on nominal interest rates and implementation lags in discretionary fiscal policy are less problematic.¹ Many developed countries, New Zealand included, delivered unprecedented fiscal support in the wake of the COVID pandemic, after the limits of conventional monetary policy were reached. Understanding the impact of discretionary fiscal policy supports the effective design and implementation of future policy interventions.

Discretionary fiscal policy's effects on GDP are typically measured through fiscal multipliers, which measure the dollar change in GDP for a dollar change in fiscal stimulus. Fiscal multipliers are affected by many factors, including the degree of trade openness in open economies (imports represent a leakage that has the potential to lower fiscal multipliers) and the extent to which monetary policy responds to or accommodates fiscal policy. In this paper I focus attention on the important role monetary policy plays in the determination of fiscal multipliers.

Monetary policy rules or reaction functions capture, in mathematical form, the way central banks respond to deviations of inflation from target and output from trend. Their specification and parameterisation describes the extent to which central banks respond to, or accommodate, fiscal shocks.

Monetary policy is more accommodative to demand shocks, including government spending shocks, when nominal interest rates are constrained at the lower bound. When the lower bound is endogenously binding (determined by economic conditions), the central bank's reaction function affects the degree of accommodation provided. At the effective lower bound, monetary policy is often represented by a rule guiding the shadow interest rate. The shadow interest rate represents the unobserved counterfactual interest rate that would be set in the absence of the effective lower bound binding. The shadow interest rate rule mirrors how the interest rate is set by the central bank in normal times. The shadow interest rate determines entry to and exit from the lower bound and the length of time that policy interest rates are expected to remain at the lower bound. Central banks can also commit to keeping interest rates at the lower bound for a fixed period of time, longer than their usual reaction function would suggest, as a form of monetary policy stimulus. This is sometimes referred to as calendar-based Odyssean forward guidance (see Jones et al. 2020 and Del Negro et al. 2023 for example).² Even after the economy exits the lower bound, the shadow interest rate and central bank's reaction function continue to influence outcomes because of consumers' and investors' forward-looking expectations.

In this paper I calculate government consumption multipliers for New Zealand using an estimated, small open economy, monetary-fiscal, dynamic stochastic general equilibrium

¹ A stronger case can be made for using discretionary fiscal policy in deep and prolonged recessions because there is less likelihood that the stimulus will arrive after the recession has ended.

² See Campbell et al. (2012) for a discussion of the different types of forward guidance.

(DSGE) model under four different monetary policy assumptions. These assumptions include: 1) monetary policy in normal times; 2,3) monetary policy with an endogenously binding lower bound under two different shadow interest rate assumptions; and 4) when the interest rate is pegged, which proxies for calendar-based Odyssean forward guidance. The choice of 2,3) follows on from the literature (see Hills & Nakata 2018, for example).

My empirical estimates suggest government consumption multipliers are larger at the lower bound, but smaller than 1, except when the monetary authority is able to commit to keeping rates fixed for at least two years. While New Zealand only spent a relatively short period of time at the lower bound during the COVID pandemic, the lower bound remains a very real impediment on future monetary policy, especially if the world returns to a low interest rate environment after the post COVID inflation has dissipated, as some have predicted (see International Monetary Fund 2023).

I develop a normalisation procedure in this paper that allows parameter uncertainty to be incorporated into the calculation of fiscal multipliers at the endogenously binding lower bound. Fiscal multipliers are usually calculated at the endogenously binding lower bound by creating a scenario where the economy is driven to the lower bound by a sequence of negative demand shocks. Incorporating parameter uncertainty into the analysis means producing a large number of scenarios under different model parameterisations. Changes in the model's parameterisation mean different sequences of shocks are required to bring the economy to the lower bound and some sort of normalisation is necessary to make these simulations comparable. My normalisation procedure imposes the same interest rate path on all parameterisations of the model prior to the lower bound binding using conditional forecasting techniques.

I use parameter sensitivity tools to better understand the model's properties. In particular, I use prior predictive analysis to understand the range of government consumption multipliers implied by both prior parameter uncertainty and the model's specification, and I use Monte Carlo filtering to determine which parameter regions are more likely to deliver larger government consumption multipliers. In both sets of exercises I investigate parameter uncertainty in the model's (monetary and fiscal) policy parameters, which can be altered by policymakers, and the deep parameters, which affect the innate behaviour of firms and households and are assumed to be invariant to policy changes.

I show that government consumption multipliers are smaller than 1 in New Zealand because it is an open economy with automatic stabilisers that moderate the effects of discretionary fiscal policy. I also show, through a simulation exercise, that many of the features that contribute to larger government consumption multipliers, like weaker automatic stabilisers and monetary policy that is less responsive to deviations of inflation and output from target, are also features that diminish the economy's ability to absorb economic shocks. To express this another way, government consumption multipliers are likely to be larger in economies with weaker stabilisation properties. This presents a trade-off between enhancing the effects of discretionary fiscal policy at the expense of weakening the economy's stabilisation properties.

The global financial crisis (GFC) reignited interest in discretionary fiscal policy as a macroeconomic stabilisation tool. Many developed countries experienced large and prolonged recessions, coupled with a binding lower bound constraint on interest rates. This led to calls for governments to make more use of activist discretionary fiscal policy.³

³ Like Auerbach et al. (2010), I use the term "activist" to describe discretionary fiscal policies that are deliberately used to stimulate the economy in an economic downturn, as opposed to "active" fiscal policy, which specifically refers to fiscal policies that do not respond sufficiently to debt to cover the government's real interest payments (see Leeper 1991).

In 2009, in response to the GFC, the United States government implemented the American Recovery and Reinvestment Act (ARRA). At a total cost of \$840 billion, this fiscal stimulus package was equal to 5.7% of GDP, a sizeable intervention at the time (see Dupor 2017).⁴ Starting in 2008, European Union countries implemented the European Economic Recovery Plan (EERP), a fiscal stimulus package that amounted to a more modest 1.9% of euro area GDP (see Coenen et al. 2013). Prior to the GFC, during the great moderation, there was ample monetary policy space, which meant monetary policy took the lead in cushioning economic shocks and business cycle management, with automatic fiscal stabilisers operating in the background. Fiscal policy in the US in the 1990s was largely preoccupied with deficit and debt reduction, explaining at least in part activist fiscal policy's absence from the great moderation (see Blinder 2022, for a more comprehensive history of US fiscal policy). A similar pattern of public debt reduction occurred in New Zealand in the 1990s and early 2000s. There is also evidence that economic shocks were smaller during the great moderation period (see Justiniano & Primiceri 2008, for example), which may have influenced the monetary-fiscal policy stabilisation mix. There may, for example, be less need for activist discretionary fiscal policy in response to smaller shocks and smaller recessions. Somewhat unusually, New Zealand only reached the lower bound on interest rates during the COVID pandemic.

Following the GFC, theoretical arguments were put forward for larger fiscal multipliers at the lower bound, supported by a new generation of macroeconomic models that had a meaningful role for both monetary and fiscal policies. A number of studies, including Cogan et al. (2010), Cwik & Wieland (2011), Coenen et al. (2012), Coenen et al. (2013), Drautzburg & Uhlig (2015) and Zubairy (2014), used DSGE models to evaluate the GDP impacts of the fiscal packages that were deployed in the US and Europe in response to the GFC. Some of these studies find multipliers lower than 1 and use this as justification for advocating against discretionary fiscal policy as a stabilisation tool, while others make the point that in particularly deep recessions, positive multipliers justify using fiscal policy to prevent a complete collapse of economic activity.

A number of studies have calculated fiscal multipliers using DSGE models when monetary policy is constrained by the lower bound. Many of them find government spending multipliers that are larger at the lower bound, exceeding 1. Much of the fiscal policy literature focuses on large closed economies. Using a simple closed economy DSGE model, Christiano et al. (2011) find government spending multipliers increase with the output cost (the cumulative negative output gap) and the duration of the lower bound. They also consider implementation lags and find government spending that occurs at the lower bound has larger multipliers than government spending that is delayed and occurs outside the lower bound period.

Eggertsson (2011) looks at fiscal multipliers in a simple closed economy New Keynesian DSGE model and finds government spending multipliers that are larger at the lower bound, also exceeding 1. In contrast, he finds capital and labour tax multipliers are positive at the lower bound, which indicates tax cuts on capital and labour income could be contractionary when interest rates are constrained. Cuts to labour and capital taxes increase aggregate supply, which increases deflationary pressures at the lower bound, causing real interest rates to increase.⁵ Woodford (2011) also looks at the factors that determine the size of government expenditure multipliers. He shows that government expenditure multipliers will always be less than 1 in the simple neoclassical model. However, introducing nom-

⁴ This is relative to 2008 US GDP, which was \$14.77 trillion.

⁵ Eggertsson (2010) refers to this as the paradox of toil. This is a direct response of implementing policies that increase aggregate supply at the lower bound when the real problem is a lack of aggregate demand. Reducing taxes on consumption and investment, and increasing government spending are all consistent with increasing aggregate demand and generating positive multipliers at the lower bound.

inal rigidities in both prices and wages introduces countercyclical markups which allow expenditure multipliers to exceed 1. Woodford (2011) also finds monetary policy is a key determinant in the size of fiscal multipliers. In normal times multipliers are likely to be less than 1, while they can exceed 1 when monetary policy is constrained at the lower bound.

Many of the studies that find multipliers greater than 1 at the lower bound rely on specifications of the shadow interest rate rule that are not history dependent. History dependence in a monetary policy context, means current monetary policy responds to both current and past economic conditions. When monetary policy is history dependent, future monetary policy will continue to respond to current economic conditions and bygones will not be bygones. Woodford (2003) has shown the stabilisation benefits of history dependent monetary policy in forward looking models. In normal times, interest rate rules with smoothing (i.e., rules that are a function of the lagged interest rate) embody history dependence. Interest rate smoothing in the central bank's reaction function usually implies current interest rates respond to a geometrically declining sum of current and historical deviations of inflation and output from their respective targets. This is because the lags of the interest rate contain information about past deviations of inflation and output from their respective targets. They also imply an expectation that future monetary policy will continue responding to current deviations of inflation and output from their respective targets.

At the lower bound there are at least two ways of expressing smoothing in shadow rate rules that are consistent with the central bank's reaction function in normal times.⁶ The smoothing term in an otherwise identical shadow rate rule can be expressed as the central bank putting some weight on either the lagged actual interest rate, or the lagged shadow interest rate. Both specifications nest the central bank's reaction function in normal times. The choice of smoothing term has consequences for the conduct of monetary policy. Shadow rate rules that are a function of the lagged shadow rate embody history dependence at, and immediately after the economy has exited, the lower bound, while shadow rate rules that are not a function of the lagged shadow rate, do not.⁷ When the economy is at the lower bound, the lagged actual interest rate is equal to the lower bound, which is a constant, and as such contains no information about past economic conditions. By contrast, the shadow interest rate is normally determined by current economic conditions which means lags of the shadow rate will contain information about historical economic conditions, including economic conditions at the lower bound.

Hills & Nakata (2018) show, using a simple New Keynesian set-up, how the shadow interest rate rule affects the size of fiscal multipliers at the lower bound. When the shadow rate is a function of the lagged *shadow* rate, government spending multipliers are positive, but much smaller than 1. When the shadow interest rate is a function of the lagged *actual* interest rate, or is not a function of the lagged shadow interest rate, government spending multipliers are much larger than 1.⁸ The superior stabilisation properties of the history dependent lagged shadow rate rule reduces the impact of government spending shocks at the lower bound. This is because agents believe the central bank will use future monetary policy (after the economy has left the lower bound) to react to fiscal shocks that occurred while the economy was at the lower bound, reducing the size of government spending multipliers. This raises a possible conflict between enhancing discretionary fiscal policy at

⁶ The Reifschneider & Williams (2000) shadow rate rule, investigated in Hills & Nakata (2018), is also consistent with the central bank's behaviour in normal times.

⁷ Taylor rules that are function of the lagged actual interest rate will become history dependent as time elapses from when the economy exited the lower bound. This is because the constant interest rate at the lower bound will receive an increasingly smaller weight, with more weight put on the increasing number of periods after the economy has exited the lower bound.

⁸ Hills & Nakata (2018) explain that policy rules that are a function of the lagged shadow interest rate return interest rates to the steady state faster, offsetting the expansionary impact of government spending shocks.

the expense of weakening stabilisation policy.⁹

Little work has been done to calculate fiscal multipliers in New Zealand using estimated structural models or to calculate fiscal multipliers at the lower bound. Murray (2013) is an exception, although he models fiscal policy as a homogenous government spending variable, net of taxes, in a DSGE-like semi-structural model without government debt. Such an approach ignores the implications of the intertemporal government budget constraint, the different economic impacts that different types of government spending have on the economy, and the role distortionary taxes play in dampening government spending multipliers. On the time-series side, there is a small but growing literature that has tried to quantify government consumption multipliers in New Zealand using Vector Autoregression (VAR) models. Starting with Parkyn & Vehbi (2014), there have been a number of papers estimating government consumption multipliers in New Zealand, including Hamer-Adams & Wong (2018), Lyu (2021), and Haug & Power (2022). Typically these studies have found peak cumulative government consumption multipliers of between 0.42 and 0.82 in normal times. These VAR studies do not look at government consumption multipliers at the lower bound.

It's a truism that both a model's specification and its parameterisation determine the size of fiscal multipliers. DSGE models are often criticised for being too restrictive, based on tight theoretical assumptions. Both model and prior specification can rule in or rule out particular results before a model is even taken to the data. This paper addresses this criticism by conducting parameter sensitivity exercises to understand which parameters, or parameter combinations are important for obtaining particular results. Prior predictive analysis has been used by Leeper et al. (2017) to better understand when government spending multipliers are likely to be larger than 1.¹⁰ Prior predictive analysis is a type of specification analysis, that investigates the range of results a model can produce based on parameter draws from the model's multivariate prior distribution. It allows practitioners to determine the range of results that should be expected before a model is even taken to the data. Monte Carlo filtering, first used by Ratto (2008) in a DSGE context, is a similar tool that involves drawing parameters from plausible ranges to determine which parameters and parameter combinations are more likely to generate behaviours of interest. Behaviours need to be discrete, so that a parameter draw either generates the behaviour of interest, or it does not. Comparing the parameter distributions of the draws that generate a particular behaviour with the distributions of the draws that do not determines whether a parameter plays a role in determining the behaviour of interest.

My analysis shows government consumption multipliers in New Zealand are larger at the lower bound, compared with normal times, but still smaller than 1 in most cases. Government consumption multipliers are larger at the endogenously binding lower bound when the shadow interest rate is a function of the lagged actual interest rate due to the absence of history dependence in the monetary policy rule. Government consumption multipliers can exceed 1 if the central bank can credibly commit to holding interest rates fixed for two or more years. Prior predictive analysis indicates the range of multipliers consistent with the prior is wider than the posterior estimates, implying the data is informative about the magnitude of fiscal multipliers.

Government consumption multipliers are generally *smaller* once the underlying parameters are estimated. One exception to this observation relates to government consumption multipliers calculated at the endogenously binding lower bound when the shadow rate is a function of the lagged actual interest rate. In this case the estimated multipliers are

⁹ Alternatively, strengthening automatic stabilisers could weaken the effects of discretionary fiscal policy.

¹⁰ See Geweke (2010) for a textbook introduction to prior predictive analysis.

larger than the prior would suggest, due to more persistent risk premium shocks. These persistent shocks lead to larger and more prolonged recessions and a longer expected duration at the lower bound.

The Monte Carlo filtering exercise highlights the role that a number of parameters play in generating larger government consumption multipliers. Many of the parameter regions consistent with larger government consumption multipliers are also more likely to generate higher volatility in either GDP or inflation, or both, illustrating the trade-offs from strengthening discretionary fiscal policy at the expense of the stabilising properties of the economy. Interpreting this from a different perspective, discretionary fiscal policy is most effective in economies that are by the nature of their parameterisations less stable/more volatile. It is important to appreciate that large fiscal multipliers are a means to an end and not an end in themselves. A government can exploit larger government consumption multipliers to stabilise an economy, when the conditions that produce them arise, but it would not make sense to design other policies to amplify the effects of discretionary fiscal policy at the expense of macroeconomic stability.

The remainder of the paper is structured as follows: in Section 2, I discuss the model and the solution and the estimation methods. In Section 3, I describe fiscal multipliers and some of their determinants. In Section 4, I talk about the different monetary policy assumptions used to calculate government consumption multipliers and how they are implemented in the model. Estimated government consumption multipliers are presented in Section 5, while the results from the prior predictive analysis and Monte Carlo filtering are discussed in Sections 6 and 7, respectively. I investigate some of the implications of the features that lead to larger government consumption multipliers on stabilisation policy in Section 8. Section 9 concludes.

2. Model, Solution and Estimation

In this section, I briefly describe the model, before describing the solution and estimation methods.

2.1 Model

I investigate government consumption multipliers in New Zealand using an estimated small open economy monetary-fiscal DSGE model. The model is reasonably standard, based on the small open economy model of Leeper et al. (2011), which shares many features with Smets & Wouters' (2007) benchmark DSGE model. I add local currency pricing following Adolfson et al. (2005) to better match the relative volatilities of the exchange rate and tradeables inflation. I also add government investment and unemployment to the model, following Baxter & King (1993) and Galí (2011) respectively. A version of the model is used by Binning (2024) to quantify the role of automatic stabilisers in New Zealand.

The model has a representative Ricardian household, a representative rule of thumb household, intermediate goods producers, importers, final goods producers, a monetary authority and a fiscal authority. The Ricardian household receives positive utility from consumption and negative utility from working. The Ricardian household supplies labour to firms and receives labour income in return. It can save, by investing in physical capital or lending to government, and it can also borrow from abroad. The Ricardian household pays taxes on its labour and capital income and on consumption purchases. It chooses wages to minimise its disutility of working, subject to a quadratic adjustment cost.

The rule of thumb household supplies labour services to firms, receiving labour income

in return. It pays taxes on its labour income and consumption purchases and receives transfers from government. The rule of thumb household consumes all income in the period it is received as it is unable to save.

Monopolistically competitive intermediate goods producers produce a differentiated intermediate good using both private and public capital, a common technology and labour. They maximise profits by choosing prices for their variety of good, subject to a quadratic adjustment cost. The perfectly competitive final goods producer combines differentiated intermediates to produce a final good. Consumption, investment, government consumption and government investment are produced by combining domestically produced tradeable goods with imported tradeable goods.

The monetary authority sets interest rates according to a Taylor-type rule in normal times. The fiscal authority provides government consumption and government investment goods and makes transfer payments to households. The fiscal authority raises revenue by taxing capital and labour income and consumption expenditure. They borrow from the Ricardian household and must adjust at least one of their fiscal instruments to ensure debt is stabilised around its long run target. A full derivation and description of the model can be found in Section E of the online technical appendix.

The model includes a number of important features for fiscal policy analysis, that do not always appear in DSGE models that are solely used for monetary policy analysis. The addition of a representative rule of thumb household provides another dimension for breaking Ricardian equivalence. The rule of thumb household is unable to save and must consume all income in the period it is received. This prevents it from saving in anticipation of higher future taxes when government spending is debt funded. The addition of a representative rule of thumb household strengthens the model's Keynesian features and provides a more realistic aggregate marginal propensity to consume. It also provides motivation for fiscal stabilisation policy, as the rule of thumb household is unable to smooth consumption and provide self insurance against adverse economic outcomes.

The model also includes distortionary taxation, which is adjusted to stabilise government debt around its long-run target. This is a more realistic assumption than using lump-sum taxation on Ricardian households to finance government spending, as there are few if any taxes or sources of government revenue that are truly non-distortionary. Government spending multipliers financed through distortionary taxation tend to be smaller when compared with government spending multipliers financed through non-distortionary sources like lump sum taxation on Ricardian households. A temporary increase in government spending in the model will initially be financed by increases in government debt. Government debt will be reduced in the medium to long-run, in line with the debt target, by increasing distortionary taxes. This has a negative impact on the household's willingness to save and work leading to a reduction in the size of fiscal multipliers when compared with non-distortionary sources of fiscal financing.

2.2 Solution

As explained in the next section on estimation, I linearise the model for estimation purposes and use a non-linear solution when calculating government consumption multipliers. I use the efficient implementation of Chris Sims' gensys solver developed by Lee & Park (2020) to solve the linearised model, resulting in significant speed gains during estimation. I calculate government consumption multipliers at the lower bound, as well as normal times.

Imposing an occasionally binding lower bound constraint on the model introduces a significant non-linearity which must be solved using a non-linear solution method. I use the extended path algorithm to solve the full non-linear model. This is a commonly used and efficient method for solving large non-linear rational expectations models and has been widely used for solving models with a binding lower bound constraint.¹¹ I use the efficient extended path routines developed by Binning (2022) in Matlab to solve the model. These routines use symbolic derivatives to solve the model with occasionally binding constraints. They also allow conditional forecasting to be incorporated into the solution. I make use of conditional forecasting to normalise the interest rate tracks when incorporating parameter uncertainty into the calculation of fiscal multipliers when the lower bound on interest rates binds endogenously. This is discussed in more detail in Section 4.

2.3 Estimation

The model is estimated using Bayesian methods on New Zealand data covering the period from 1994Q1 to 2019Q4. Parameters affecting the steady state or that are difficult to estimate have been calibrated. Appendix B.1 discusses how such parameters have been calibrated, with Table 8 listing the full set of calibrated parameters and their values. The remaining parameters are estimated using the linearised model. It would be preferable to estimate these parameters using the full non-linear model, as this is the model used to calculate government consumption multipliers, but this is considerably more difficult to do due to the model's size and the fact that it is an open economy model.¹²

I estimate the model using 19 quarterly macroeconomic time series as observable variables. These are real GDP, consumption, investment, government consumption, government investment, exports, interest rates, CPI inflation, wage inflation, the change in the nominal exchange rate, the unemployment rate, transfer payments, labour tax revenue, capital tax revenue, consumption tax revenue, government debt to GDP, foreign GDP, foreign interest rates and foreign inflation. All levels/log-levels series and the domestic nominal interest rate are Hodrick Prescott filtered, while all inflation rates are de-measured and the foreign nominal interest rate is linearly detrended. A full description of the data and the transformations can be found in Appendix A. Data from before 1994 is excluded from the sample because it represents a different economic regime, with CPI inflation much higher in the 1980s and early 1990s before inflation targeting was implemented. Data from 2020 onwards is excluded because it is affected by the COVID pandemic and it would require both non-linear solution and estimation techniques to handle the effective lower bound on interest rates.

Confounding effects around the time of the GFC make it more difficult to accurately determine the response of labour taxes to the business cycle. A number of tax changes occurred in New Zealand between 2008 and 2011 which shifted the composition from labour taxation to higher consumption taxation. These changes occurred during the GFC, when labour tax revenues would have also fallen due to weaker economic activity. As a consequence the estimated coefficient on the output gap in the labour tax rule may overstate the response of the labour tax rate to the business cycle. To understand how this may affect the results, I run some sensitivity tests where I set the labour tax elasticity with respect to the output gap to more closely match the implied OECD estimates for automatic stabilisers in New Zealand. The results of these sensitivity tests are discussed in Section 5.

¹¹ See Cogan et al. (2010), Cwik & Wieland (2011) and Coenen et al. (2021) for example.

¹² Estimating non-linear DSGE models using state-space methods imposes cointegrated trends on the data. These trends are not always consistent with the data. Larger models, especially open economy models, have more cointegrating trends to match, increasing the scope for the trends in the data to be misspecified relative to the data.

In the spirit of Del Negro & Schorfheide (2008) and Beneš & Andrieu (2013), I use system priors to impose additional constraints on the conventional parameter priors to ensure that consumption increases after a positive technology shock.¹³ I sample from the posterior distribution using the Metropolis Hastings algorithm, where I take 6 million draws and I burn the first million. Following Adolfson et al. (2007), all parameters are transformed into unbounded parameter space during estimation, improving the Metropolis Hastings' sampling properties. The estimated parameters along with their respective priors can be found in Tables 10 to 12 in Appendix B.2.

3. Fiscal Multipliers

In this section I define the concept of fiscal multipliers, talk about their interpretation, list some of the factors that determine the size of fiscal multipliers and discuss how these factors are captured in the model. Put plainly, fiscal multipliers represent the dollar change in GDP for a dollar change in discretionary government spending or tax revenue. Fiscal policymakers and their advisors are concerned with the magnitude of fiscal multipliers, wanting to know under what conditions discretionary fiscal stimulus will have the maximum impact. They are also concerned with their impact on private sector activity. When government spending multipliers are positive, they indicate that government intervention contributes to an increase in GDP and when multipliers are larger than 1, they indicate government intervention contributes to an increase in private sector activity. The interpretation of the magnitudes of government consumption multipliers can be better illustrated through a simple exercise using the standard aggregate demand relationship,

$$\begin{aligned} Y_t &= C_t + I_t + X_t - M_t + G_t + G_{I,t}, \\ &= Y_t^p + G_t + G_{I,t}, \end{aligned}$$

where C_t is consumption, I_t is investment, X_t is exports, M_t is imports, G_t is government consumption, $G_{I,t}$ is government investment and Y_t^p is the private sector component of aggregate demand. The government consumption multiplier on impact is defined as,

$$\frac{\partial Y_t}{\partial G_t} = \frac{\partial Y_t^p}{\partial G_t} + 1.$$

When the government consumption multiplier is less than 1, private economic activity is crowded out by government activity,

$$\frac{\partial Y_t}{\partial G_t} < 1, \quad \text{if} \quad \frac{\partial Y_t^p}{\partial G_t} < 0.$$

When the multiplier is equal to 1, private economic activity is neither crowded in or crowded out by government activity,

$$\frac{\partial Y_t}{\partial G_t} = 1, \quad \text{if} \quad \frac{\partial Y_t^p}{\partial G_t} = 0.$$

When the multiplier is larger than 1, private activity is crowded in by government,

$$\frac{\partial Y_t}{\partial G_t} > 1, \quad \text{if} \quad \frac{\partial Y_t^p}{\partial G_t} > 0.$$

There are numerous fiscal and economic factors that determine the size of fiscal multipliers. Some of the most important factors identified by Batini et al. (2014) and Ramey (2019) are listed below in no particular order,

¹³ Under certain parameterisations of the model, consumption may fall after a technology shock due to the response of the rule of thumb household. I rule this out by adding a penalty to the posterior for parameterisations that lead to a fall in consumption in response to a positive technology shock.

1. The persistence of the fiscal intervention
2. The type of spending or taxes that is changed
3. How the policy is financed
4. Whether it is anticipated
5. How the policy is distributed across potentially heterogeneous agents
6. How monetary policy reacts (the degree of monetary accommodation to fiscal shocks)
7. The state of the economy (business cycle) when the policy takes effect
8. The degree of labour market rigidity
9. The size of automatic stabilisers
10. The level of public debt
11. The exchange rate regime and degree of (trade) openness
12. The level of development
13. The quality of public expenditure management and revenue administration.

Structural models can be used to investigate the impact on fiscal multipliers of items 1 through 11.¹⁴ Due to space considerations, I limit analysis in this paper to calculating government consumption multipliers for New Zealand. I look specifically at the GDP response to unexpected government consumption shocks financed through debt and labour income taxes under different monetary policy assumptions. I investigate government consumption multipliers in normal times when monetary policy is set according to a Taylor-type rule and when interest rates are constrained at the effective lower bound, as was the case recently following the COVID outbreak. These monetary policy assumptions and their implementation in the model are detailed in the next section.

The model used in this paper is rich enough to investigate how many of factors listed by Baitini et al. (2014) and Ramey (2019) affect government consumption multipliers. The model features autoregressive government consumption shocks, which allows the persistence of government consumption to be factored into the calculation of government consumption multipliers. The inclusion of a rule of thumb household allows the distribution of fiscal policies over heterogeneous agents to be captured in the calculation of fiscal multipliers. Differentiated labour and quadratic adjustment costs introduce nominal rigidities into the model, the strength of which can be controlled by setting the weight on the adjustment costs. The fiscal rules used in the model can respond to the output gap, which allows the effects of automatic stabilisers to be included in the calculation of government consumption multipliers. Final goods are also produced using imported intermediate goods. Varying the home bias parameters captures the degree of trade openness in the model. I investigate the impact of these factors on government consumption multipliers in more depth using Monte Carlo filtering in Section 7.

4. Constructing Fiscal Multipliers Under Different Monetary Policy Assumptions

One of the key factors affecting the size of fiscal multipliers is the monetary policy response. In this paper I investigate government consumption multipliers under four different monetary

¹⁴ It is more difficult to capture qualitative issues like the level of development and the quality of public expenditure management and revenue administration in a meaningful way, in a structural model.

policy settings. These include monetary policy in normal times, set according to a Taylor-type rule, two different specifications of the shadow interest rate when interest rates are constrained at the lower bound, and monetary policy set according to an interest rate peg.

During the COVID-19 pandemic, monetary policy in New Zealand was constrained by the lower bound on nominal interest rates. While New Zealand only spent 6 quarters at the lower bound, much shorter than the 7 years the US spent at the lower bound after the GFC, the lower bound on nominal interest rates remains a likely impediment on future monetary policy. The impact of the lower bound on stabilisation will be more acute if the world returns to a low interest rate environment after the post COVID inflation dissipates, as some have hypothesised (see International Monetary Fund 2023). As a consequence, it is important for policymakers, both monetary and fiscal, to understand the implications of different monetary policy settings on fiscal policy at the lower bound.

The shadow interest rate and the central bank's reaction function determine entry to and exit from the lower bound, and its expected duration, when the lower bound on interest rates is endogenously binding.¹⁵ In this context, the shadow interest rate is an unobserved interest rate calculated by applying the monetary authority's interest rate rule to actual GDP and inflation outturns, when the economy is at the lower bound.¹⁶ Under these assumptions, economic conditions determine when the lower bound does and does not bind. I investigate two specifications of the shadow rate that have been shown by Hills & Nakata (2018) to affect the size of government consumption multipliers. In the first specification, the shadow interest rate is a function of the lagged *shadow* interest rate. In the second specification, the shadow rate is a function of the lagged *actual* interest rate. These specifications build different amounts of history dependence into monetary policy both at the lower bound and immediately after the economy has exited the lower bound. History dependence has been shown to improve monetary policy's stabilisation properties in other contexts.

These different specifications of the shadow rate imply different behaviour by the central bank at the lower bound, and in the periods immediately after the economy has exited the lower bound. The lack of history dependence when the shadow rate is a function of the lagged actual interest rate is consistent with a central bank that does not use monetary policy to directly respond to events that occurred while the economy was at the lower bound in the periods after the economy has exited the lower bound. This implies less macroeconomic stabilisation and deeper recessions while the economy is at the lower bound as the exercise in Section 5.1 illustrates. A central bank may choose to behave in this way if they want to be more accommodative (less reactive) to fiscal policy while at, and immediately after exiting the lower bound. Alternatively the central bank may lack the credibility to signal that they will respond and continue to respond to deviations of inflation from target and output from trend that occurred at the lower bound, after the economy has exited the lower bound.

A shadow rate rule that is a function of the lagged shadow interest rate is history dependent and is consistent with a central bank that uses monetary policy in the periods after it has exited the lower bound to respond directly to events that occurred while the economy was at the lower bound. Implementing monetary policy in this way provides better macroeconomic stabilisation and shallower recessions when the economy is at the lower bound as the exercise in Section 5.1 demonstrates. A central bank may operate monetary policy in this way if they can credibly signal that they will respond to deviations of inflation from

¹⁵ An endogenously binding lower bound means entry, exit and the duration of the lower bound are determined by the central bank's reaction function, which is a function of current and potentially past and future economic conditions.

¹⁶ Away from the lower bound, the shadow interest rate coincides with the actual interest rate.

target and output from trend that occurred at the lower bound, after the economy has exited the lower bound. Interest rate smoothing in normal times is often associated with central banks building credibility by making gradual policy changes, and avoiding rapid policy reversals (see Coibion & Gorodnichenko 2011). Shadow rate smoothing that is a function of the lagged shadow interest rate can be seen as an extension of this type of policy. A shadow rate rule that is a function of the lagged shadow interest rate is also consistent with a central bank that is less accommodative (more reactive) to fiscal policy while the economy is at the lower bound.

The interest rate peg proxies for calendar-based Odyssean forward guidance. Odyssean forward guidance represents the situation where a central bank announces and commits to a deviation of monetary policy from their usual behaviour. Using the same terminology as Jones et al. (2020), calendar-based Odyssean forward guidance defines the situation where a central bank commits to keeping interest rates fixed at the lower bound for a specified period of time, independent of economic conditions.¹⁷

These four different monetary policy assumptions can be expressed mathematically as follows,

1. Interest rates are set according to a Taylor-type rule in normal times,

$$R_t = (R_{t-1})^{\rho_R} \left(R \left(\frac{\pi_t}{\pi} \right)^{\kappa_\pi} \left(\frac{Y_t}{Y} \right)^{\kappa_Y} \right)^{1-\rho_R}, \quad (1)$$

where R_t is the gross interest rate, π_t is the gross CPI inflation rate, Y_t is output and R , π and Y are their respective steady state values.¹⁸

2. A state dependent (endogenously determined) binding lower bound,

$$R_t = \max(R_{ELB}, R_t^*), \quad (2)$$

where R_{ELB} is the effective lower bound on interest rates and R_t^* is the shadow interest rate. The shadow rate, which is a function of economic conditions, determines when the lower bound constraint binds. I investigate two different assumptions about the determination of the shadow rate:

- 2.a) The shadow rate as a function of the lagged *shadow* rate,

$$R_t^* = (R_{t-1}^*)^{\rho_R} \left(R \left(\frac{\pi_t}{\pi} \right)^{\kappa_\pi} \left(\frac{Y_t}{Y} \right)^{\kappa_Y} \right)^{1-\rho_R}. \quad (3)$$

- 2.b) The shadow rate as a function of the lagged *actual* interest rate,

$$R_t^* = (R_{t-1})^{\rho_R} \left(R \left(\frac{\pi_t}{\pi} \right)^{\kappa_\pi} \left(\frac{Y_t}{Y} \right)^{\kappa_Y} \right)^{1-\rho_R}. \quad (4)$$

3. A k period interest rate peg (proxying for calendar-based Odyssean forward guidance),

$$R_t = \begin{cases} R & \text{for } t = 1, \dots, k \\ R_t = (R_{t-1})^{\rho_R} \left(R \left(\frac{\pi_t}{\pi} \right)^{\kappa_\pi} \left(\frac{Y_t}{Y} \right)^{\kappa_Y} \right)^{1-\rho_R} & \text{for } t > k \end{cases}. \quad (5)$$

¹⁷ Arguably, the Reserve Bank of New Zealand made use of calendar-based Odyssean forward guidance when they committed to keep interest rates at 0.25 % for at least 12 months during the COVID pandemic (see Kengmana 2021, for the Reserve Bank's own assessment of how monetary policy was implemented).

¹⁸ The gross rate of inflation is $\pi_t = \frac{P_{C,t}}{P_{C,t-1}}$, where $P_{C,t}$ is the CPI index which is assumed to be the same as the consumption deflator in the model.

I use the steady state interest rate, R , as the interest rate peg to isolate the impact of accommodative monetary policy from any additional non-linear effects that may occur from imposing the lower bound in normal times. This is the approach taken by Leeper et al. (2017) and Sims & Wolff (2018) amongst others. An interest rate pegged at the steady state level is accommodative in the sense that monetary policy is unable to respond to increases in inflation and GDP while the interest rate is fixed, so it is unable to moderate the effects of the government spending shock.

I demonstrate how the different interest rate rules embed history dependence. Starting with monetary policy in normal times, the interest rate rule in equation (1) can be expressed in log-linearised terms as,

$$\hat{R}_t = \rho_R \hat{R}_{t-1} + (1 - \rho_R) [\kappa_\pi \hat{\pi}_t + \kappa_Y \hat{Y}_t], \quad (6)$$

where $\hat{X}_t = \log\left(\frac{X_t}{\bar{X}}\right)$ for R_t , π_t and Y_t . Repeated back substitution of equation (6) leads to,

$$\hat{R}_t = \sum_{h=0}^{\infty} \rho_R^h (1 - \rho_R) [\kappa_\pi \hat{\pi}_{t-h} + \kappa_Y \hat{Y}_{t-h}], \quad (7)$$

which shows the current interest rate gap is determined by the geometrically weighted sum of all inflation and output gaps up to the current period. This means current interest rates are still responding to past deviations of inflation and output from their respective targets, and that future interest rates are expected to respond to current deviations of inflation and output from their respective targets.

When the lower bound on interest rates is endogenously binding, equation (2) and the value of the shadow rate determine when the lower bound binds. Equation (2) can be rewritten in log deviation terms as follows,

$$\hat{R}_t = \max \left(\log \left(\frac{R_{ELB}}{R} \right), \hat{R}_t^* \right). \quad (8)$$

When the shadow rate is a function of the lagged shadow interest rate, the shadow interest rate (equation 3) can be written in log linear terms,

$$\hat{R}_t^* = \rho_R \hat{R}_{t-1}^* + (1 - \rho_R) [\kappa_\pi \hat{\pi}_t + \kappa_Y \hat{Y}_t]. \quad (9)$$

Repeated back substitution of equation (9) leads to,

$$\hat{R}_t^* = \sum_{h=0}^{\infty} \rho_R^h (1 - \rho_R) [\kappa_\pi \hat{\pi}_{t-h} + \kappa_Y \hat{Y}_{t-h}], \quad (10)$$

which shows when the shadow rate is a function of the lagged shadow rate, the shadow rate can be written as the geometrically weighted sum of all past historical deviations of inflation and output from their targets, including all periods at and preceding the lower bound.

By contrast, it is not possible to write the shadow rate as a function of past inflation and output gaps when the shadow rate is a function of the lagged actual interest rate, because the lagged actual interest rate at the lower bound is equal to the lower bound, which is a constant that contains no information about current or past economic conditions. The actual interest rate constrained at the effective lower bound does not encode the depth of the recession experienced.

When the shadow interest rate is a function of the lagged actual interest rate, the interest rate J periods after exiting the lower bound will be set according to,

$$\hat{R}_{t+J} = \rho_R^J \hat{R}_{ELB} + \sum_{j=1}^J \rho_R^{J-j} (1 - \rho_R) \left[\kappa_\pi \hat{\pi}_{t+j} + \kappa_Y \hat{Y}_{t+j} \right], \quad (11)$$

where forward(/back) substitution can be used to write the interest rate as a function of the inflation and output gaps in the periods after exiting the lower bound, but not as a function of the inflation and output gaps at the lower bound or for periods preceding the lower bound. Monetary policy will become more history dependent as the length of time since exiting the lower bound increases.

The interest rate peg can also be expressed in log-linear terms,

$$\hat{R}_t = \begin{cases} 0 & \text{for } t = 1, \dots, k \\ \hat{R}_t = \rho_R \hat{R}_{t-1} + (1 - \rho_R) \left[\kappa_\pi \hat{\pi}_t + \kappa_Y \hat{Y}_t \right] & \text{for } t > k \end{cases} \quad (12)$$

where the interest rate is pegged at the steady state, which is equal to 0 when evaluated as the log deviation from the steady state. When the economy exits the interest rate peg, monetary policy is set according to a Taylor-type rule where the smoothing term is the lagged actual interest rate. The interest rate J periods after exiting the interest rate peg is determined by,

$$\hat{R}_{t+J} = \sum_{j=1}^J \rho_R^{J-j} (1 - \rho_R) \left[\kappa_\pi \hat{\pi}_{t+j} + \kappa_Y \hat{Y}_{t+j} \right], \quad (13)$$

so that interest rates are a function of the output and inflation gaps that occur after exiting the interest rate peg, but not the output and inflation gaps that occurred while or before the interest rate is pegged. This is because the pegged interest rate is a constant containing no information about economic conditions before or during the peg. Monetary policy becomes more history dependent as the length of time since exiting the interest rate peg increases.

Alternatively, if the central bank followed a Taylor-type rule that was a function of the lagged shadow rate after exiting the interest rate peg, where the shadow rate is also a function of the lagged shadow rate (like equation (3)), monetary policy would be history dependent. Taylor-type rules that are a function of the lagged shadow interest rate are not typically used in the literature when modelling interest rate pegs.

By contrast, when the shadow interest rate is a function of the lagged shadow interest rate, the interest rate J periods after exiting the lower bound is set according to,

$$\hat{R}_{t+J} = \rho_R^J \hat{R}_t^* + \sum_{j=1}^J \rho_R^{J-j} (1 - \rho_R) \left[\kappa_\pi \hat{\pi}_{t+j} + \kappa_Y \hat{Y}_{t+j} \right]. \quad (14)$$

Substituting equation (10) in for \hat{R}_{t-1}^* gives,

$$\begin{aligned} \hat{R}_{t+J} &= \sum_{h=0}^{\infty} \rho_R^{J+h} (1 - \rho_R) \left[\kappa_\pi \hat{\pi}_{t-h} + \kappa_Y \hat{Y}_{t-h} \right] \dots \\ &\quad \dots + \sum_{j=1}^J \rho_R^{J-j} (1 - \rho_R) \left[\kappa_\pi \hat{\pi}_{t+j} + \kappa_Y \hat{Y}_{t+j} \right], \end{aligned} \quad (15)$$

$$= \sum_{h=0}^{\infty} \rho_R^h (1 - \rho_R) \left[\kappa_\pi \hat{\pi}_{t+J-h} + \kappa_Y \hat{Y}_{t+J-h} \right], \quad (16)$$

so that the actual interest rate set once the economy has exited the lower bound is a function of the inflation and output gaps in all preceding periods, including the inflation and output gaps while at and before the lower bound.

I solve the model using the efficient extended path algorithm developed by Binning (2022). The max operator in equation (2) is implemented by introducing an indicator variable, $\mathbf{Z}_{1,t}$, so that,

$$R_t = \mathbf{Z}_{1,t} R_t^* + (1 - \mathbf{Z}_{1,t}) R_{ELB}, \quad (17)$$

where the indicator function takes the values,

$$\mathbf{Z}_{1,t} = \begin{cases} 0 & \text{if } R_t^* \leq R_{ELB} \\ 1 & \text{if } R_t^* > R_{ELB} \end{cases}. \quad (18)$$

The indicator function has a 1 subscript indicating that it is the first of two monetary policy indicator functions used in the model. The t subscript references the indicator function's ability to take different values in different time periods, depending on economic conditions.

As discussed in Binning (2022), this specification allows symbolic derivatives to be used with occasionally binding constraints in the extended path algorithm, shortening the code's execution time.

Under the interest rate peg, the interest rate is determined according to,

$$R_t = \mathbf{Z}_{2,t} R + (1 - \mathbf{Z}_{2,t}) R_t^*, \quad (19)$$

where the indicator function $\mathbf{Z}_{2,t}$ takes the values,

$$\mathbf{Z}_{2,t} = \begin{cases} 1 & \text{for } t = 1, \dots, k \\ 0 & \text{for } t > k \end{cases}. \quad (20)$$

The interest rate peg is a surprise to agents in the first period the constraint is imposed, then perfectly anticipated in all remaining simulation periods where the constraint applies.

Fiscal multipliers in normal times are typically calculated using impulse response functions as illustrated by Blanchard & Perotti (2002), Leeper et al. (2010a) and Zubairy (2014). This is because fiscal multipliers capture the GDP response to a discretionary fiscal intervention and fiscal shocks represent discretionary fiscal interventions. Similarly, fiscal multipliers can be calculated using impulse response functions when the interest rate is pegged at the steady state as illustrated by Leeper et al. (2017) and Sims & Wolff (2018). In this case the model is shocked and the interest rate is held at the steady state for k quarters.¹⁹ The impulse response underlying the fiscal multiplier is then calculated as the difference between the model perturbed with a fiscal shock and the steady state, as the steady state is equivalent to the interest rate peg in the absence of any shocks.

Calculating fiscal multipliers when the lower bound is endogenously binding requires constructing a scenario where economic conditions cause the lower bound to bind as illustrated in Gomes et al. (2015) and Lindé & Trabandt (2018). This is achieved by subjecting the economy to a sequence of negative demand shocks of sufficient size to cause the lower bound to bind. The impulse response is then constructed by creating an identical scenario, but with an unanticipated fiscal shock hitting the economy when it is at the lower bound. Subtracting the first (baseline) scenario from the second creates the impulse response function.

¹⁹ This is equivalent to adding a sequence of anticipated monetary policy shocks to the monetary policy rule to keep interest rates constant for the duration of the interest rate peg.

Under a single parameterisation of the model, calculating fiscal multipliers when the lower bound binds endogenously is a relatively straight forward exercise. With a little bit of trial and error a sequence of negative demand shocks can be found that ensures the lower bound binds for plausible horizons. However, making the lower bound bind endogenously becomes more difficult when investigating multiple parameterisations of the model, as I do in a number of the exercises in this paper. This is because changes in the model's parameterisation mean the sequence of shocks required to bring the economy to the lower bound for one model parameterisation will not be the same for other parameterisations of the model. Manually choosing sequences of shocks that bring the economy to the lower bound for each parameterisation of the model is not feasible, especially when the number of parameter draws is large.

To circumvent this problem, I normalise the interest rate track for the first 5 quarters, for all model parameterisations.²⁰ This can be carried out mechanically and quite efficiently using conditional forecasting techniques, which can be used in combination with the extended path algorithm, as illustrated in Binning (2022). In the general case with underidentified shocks (there are more shocks than forecast conditions) there will be infinitely many shock combinations consistent with a set of forecast conditions. Conditional forecasting techniques choose sequences of the most likely shocks (in a least squares sense) consistent with the forecast conditions imposed on the model. When conditional forecasting techniques are used with exactly identified shocks, there is one shock for each forecast condition and the resulting sequence of shocks required to fit a set of forecast conditions is unique. For simplicity's sake, I fit the interest rate track using the conditional forecasting algorithm with exactly identified demand shocks.²¹ I impose the same interest rate track on each parameterisation of the model, in the absence of the endogenously binding lower bound constraint, to find the sequence of negative demand shocks that brings the economy to the lower bound. This avoids any issues that may arise when combining conditional forecasting with the lower bound constraint. It also allows comparability between the scenarios under the different shadow rate assumptions, as the shock sequences used to produce the multipliers will be the same in both scenarios for the same parameterisation of the model, because the shadow interest rate rules are the same prior to the effective lower bound bounding.²²

Starting from the steady state and using a model without a lower bound constraint on interest rates, I impose a linear path on the nominal interest rate that sees it fall from 3% (its steady state value) to -0.5% over 5 quarters. I then back out the sequence of negative demand shocks that matches the imposed interest rate path and feed these into the same parameterisation of the model where the lower bound binds endogenously to create the lower bound scenario. I produce a second scenario using the same model and the same sequence of negative demand shocks that bring the economy to the lower bound, but I add a government consumption shock in the second period the lower bound binds. Subtracting the first scenario from the second creates the fiscal impulse response used to construct the fiscal multiplier. While the depth and duration of the recession and the duration of the binding lower bound will differ across parameterisations, the interest rate path for the first 5 quarters will be identical across all models, ensuring comparability.

²⁰ The normalisation horizon should be based on the number of periods it takes the economy to reach the lower bound. In this case I impose a path that takes 5 quarters for the economy to reach the lower bound. Other paths that reach the lower bound over a different time span could also be set.

²¹ It is also possible to fit the interest rate track using the conditional forecasting algorithm in the more general case with overidentified shocks using the code from Binning (2022). However, I consider that it makes more sense to restrict attention to just the demand shocks or a subset of the demand shocks, as positive supply shocks would likely be required to bring the economy to the lower bound, which is inconsistent with recent experience.

²² I use the same parameter draws to produce the government consumption multipliers.

I fit the interest rate track using the Smets & Wouters (2007) risk premium shock, which is the closest shock in the model to a true business cycle shock. This requires introducing a new variable, $\tilde{\varepsilon}_{AB,t}$, which is an endogenous risk premium shock, chosen by the algorithm to match the interest rate track imposed on the model. This variable is endogenous in the sense that the shock is chosen to match the endogenous interest rate, R_t , with the exogenous interest rate track, \mathbb{R}_t . This means that a change in the interest rate rule, or any other equations that affect the interest rate response, will change the value of $\tilde{\varepsilon}_{AB,t}$ required to match a given exogenous interest rate track. Likewise, changes in the exogenous interest rate track itself will change the sequence of endogenous risk premium shocks required to fit the interest rate path. The risk premium shock process, $A_{B,t}$, is modified, so that,

$$A_{B,t} = \rho_{AB} A_{B,t-1} + \tilde{\varepsilon}_{AB,t}. \quad (21)$$

Adding an endogenous variable to the model requires adding an extra equation to the model. I augment the model with the following auxiliary equation,

$$\mathbf{X}_t (R_t - \mathbb{R}_t) + (1 - \mathbf{X}_t) (\tilde{\varepsilon}_{AB,t} - \varepsilon_{AB,t}) = 0, \quad (22)$$

where \mathbf{X}_t is an indicator variable that takes the value 1 in periods where the forecast conditions are imposed and zero in all other periods, and \mathbb{R}_t is the forecast condition on interest rates applied in period t . I assume that the shocks are unexpected so that the sequence of forecast conditions are only revealed to agents in the periods they are imposed. To produce the lower bound scenarios, I set $\varepsilon_{AB,t} = \tilde{\varepsilon}_{AB,t}$ so that the shocks that I feed into the endogenously binding lower bound scenario are equal to the sequence I find in the model without the lower bound constraint.

I calculate cumulative government consumption multipliers in this paper. Cumulative fiscal multipliers are better able to handle persistence in fiscal instruments and have become the standard metric for evaluating the impact of discretionary fiscal interventions on GDP. The cumulative government consumption multiplier in normal times T periods after the shock hits is given by,

$$M_T = \frac{\sum_{t=1}^T (Y_t(\varepsilon_{uG,1}) - Y)}{\sum_{t=1}^T (G_t(\varepsilon_{uG,1}) - G)}, \quad (23)$$

where the government consumption shock, $\varepsilon_{uG,1}$, is assumed to hit in the first period, $Y_t(\varepsilon_{uG,1})$ is period t GDP perturbed by the government consumption shock and $G_t(\varepsilon_{uG,1})$ is period t government consumption also perturbed by the government consumption shock.

The cumulative government consumption multiplier at the endogenously binding lower bound T periods after the shock hits is calculated as the difference between two lower bound scenarios. In the first scenario, a sequence of risk premium shocks brings the economy to the lower bound. The second scenario is identical to the first, with the exception of a government consumption shock which is added in the second period the economy is at the lower bound. The calculation of the government consumption multiplier discards the simulated series in the periods before the government consumption shock hits. This is represented mathematically as follows,

$$M_T = \frac{\sum_{t=1}^T (Y_t(\varepsilon_{uG,1}, \varepsilon_{AB,-4:0}) - Y_t(\varepsilon_{AB,-4:0}))}{\sum_{t=1}^T (G_t(\varepsilon_{uG,1}, \varepsilon_{AB,-4:0}) - G_t(\varepsilon_{AB,-4:0}))}, \quad (24)$$

where $Y_t(\varepsilon_{AB,-4:0})$ and $G_t(\varepsilon_{AB,-4:0})$ represent period t GDP and government consumption, respectively, in the baseline lower bound scenario and $\varepsilon_{AB,-4:0}$ is the sequence of 5 risk premium shocks in periods -4 through to 0, that bring the economy to the lower bound. The government consumption shock, $\varepsilon_{uG,1}$, is assumed to hit the economy in the first

period (this is the second period the economy is at the lower bound). $Y_t(\varepsilon_{u_G,1}, \varepsilon_{A_B,-4:0})$ and $G_t(\varepsilon_{u_G,1}, \varepsilon_{A_B,-4:0})$ represent GDP and government consumption in the lower bound scenario with the government consumption shock. The impulse response is the difference between the lower bound scenario with the government consumption shock and the baseline lower bound scenario without the government consumption shock.

5. Estimated Government Consumption Multipliers

In this section I report the results for the estimated cumulative government consumption multipliers. As mentioned in Section 4, I calculate government consumption multipliers under four different monetary policy assumptions: (i) monetary policy set in normal times according to a Taylor-type rule; (ii) and (iii) an endogenously binding lower bound constraint under two different shadow rate assumptions; and (iv) an interest peg, where the peg proxies for calendar-based Odyssean forward guidance. The shadow rate assumptions differ depending on whether smoothing in the shadow rate rule uses the lagged shadow rate or the lagged actual interest rate. I investigate four quarter and eight quarter interest pegs to understand how the duration of the interest rate peg affects the size of government consumption multipliers.²³

Before presenting results for government consumption multipliers evaluated at the endogenously binding lower bound, I present the scenarios used to calculate them. As was mentioned in Section 4, government consumption multipliers at the endogenously binding lower bound are calculated using a lower bound scenario because the lower bound is determined by economic conditions.²⁴ I normalise the simulations by imposing the same falling interest rate track on the first 5 quarters for each model parameterisation, using risk premium shocks, which are determined using conditional forecasting techniques.

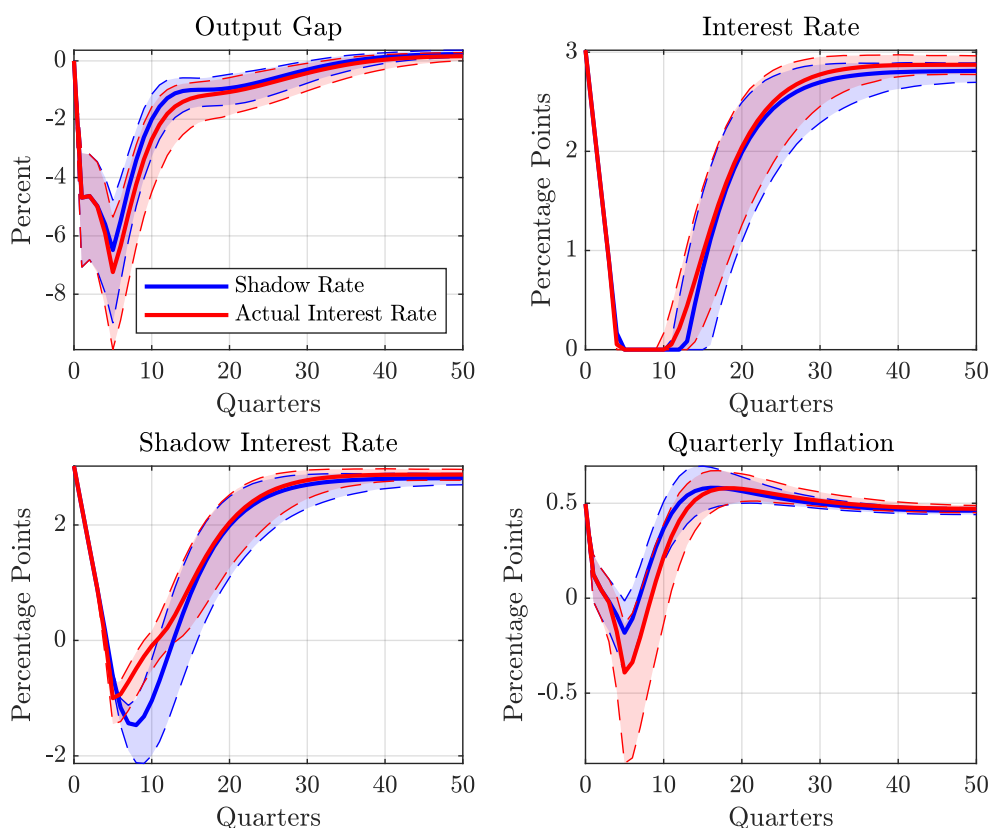
5.1 Monetary Policy Rules With Shadow Short Rates

I use the same parameter draws to construct the lower bound scenarios for both shadow rate assumptions when the lower bound on interest rates is endogenously binding. This means for each parameterisation of the model, the lower bound scenarios for both shadow rate assumptions are constructed using the same sequence of negative demand shocks. Because the sequence of shocks used to produce both scenarios is the same for each parameterisation, and the same parameter draws are used to produce both sets of scenarios, the lower bound scenarios can be directly compared to understand the economic implications of the different shadow rate assumptions when interest rates are constrained by the lower bound. The distribution for the baseline scenario across all parameterisations, for both specifications of the shadow rate are presented in Figure 1.

²³ The interest rate peg is a surprise in the period that it is announced. It is anticipated in subsequent periods.

²⁴ A similar procedure is used by Gomes et al. (2015) and Lindé & Trabandt (2018) to calculate fiscal multipliers at the lower bound.

Figure 1 – Endogenous Lower Bound Scenario: Lagged Shadow Rate



Note: Shadow Rate refers to the shadow rate being a function of the lagged shadow rate and Actual Interest Rate refers to the shadow rate being a function of the lagged actual interest rate. The dashed lines represent 99% bands capturing estimated parameter uncertainty. Solid lines represent the median of the simulations.

It takes 5 quarters for the interest rate to reach the lower bound, as per the interest rate normalisation imposed on all parameterisations of the model. The normalisation also eliminates the uncertainty band for interest rates over this period. For each parameterisation of the model, the normalisation forces the interest rate track to be the same, eliminating the variation due to parameter uncertainty.

When the shadow interest rate is a function of the lagged *shadow* interest rate, the median depth of the output gap at its deepest point is -6%, the median quarterly rate of inflation falls to -0.2% and the median interest rate track stays at the lower bound for 8 quarters.

When the shadow interest rate is a function of the lagged *actual* interest rate, the median duration and depth of the recession is larger and the fall in inflation is greater than when the shadow rate is a function of the lagged shadow rate. The median duration at the lower bound is also shorter at 6 quarters, with the economy exiting the lower bound a couple of quarters earlier. This is because the monetary authority's decision to exit the lower bound is only a function of economic conditions in the current period when the shadow rate is a function of the lagged actual interest rate.

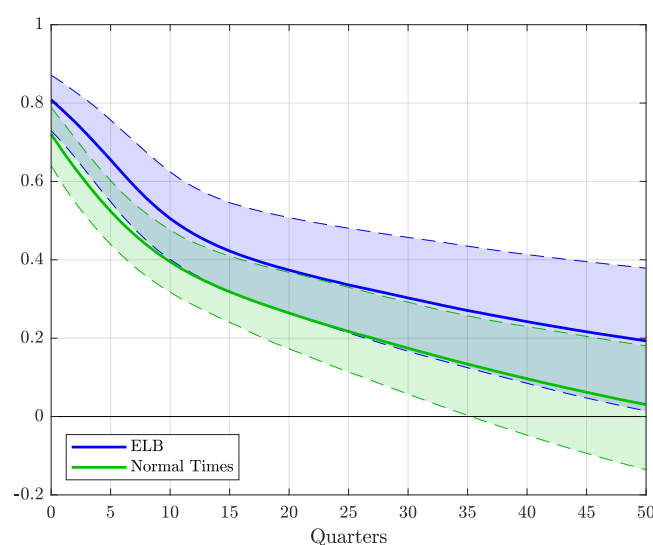
When the shadow interest rate is a function of the lagged *shadow* interest rate, the monetary authority's decision to exit the lower bound is a function of current and past economic conditions. This means the monetary authority takes into account what has occurred in all immediately preceding periods at the lower bound when deciding whether to

exit the lower bound. As a consequence, the monetary authority compensates to some extent for the weaker GDP and lower inflation at the lower bound by holding interest rates at the lower bound for longer. Forward looking agents in the model understand this and take the monetary authority's additional stimulus into account when determining their own behaviour, resulting in smaller falls in GDP and inflation, and less volatility at the lower bound. This point will be discussed in more detail in Section 8 in relation to history dependent monetary policy and the stabilisation properties of the economy.

To calculate the government consumption multiplier, I create an identical scenario, perturbing the model with a positive government consumption shock in the second period the economy is at the lower bound (quarter 6 in Figure 1). I then subtract the first scenario from the second to construct the impulse responses used to calculate the government consumption multipliers.²⁵

The distributions of the cumulative government consumption multipliers calculated at the endogenously binding lower bound are plotted against the government consumption multiplier in normal times in Figures 2 and 3. The government consumption multipliers in Figure 2 are calculated at the lower bound when the shadow rate is a function of the lagged shadow rate. The government consumption multipliers in Figure 3 are calculated at the lower bound with the shadow rate set as a function of the lagged actual interest rate.

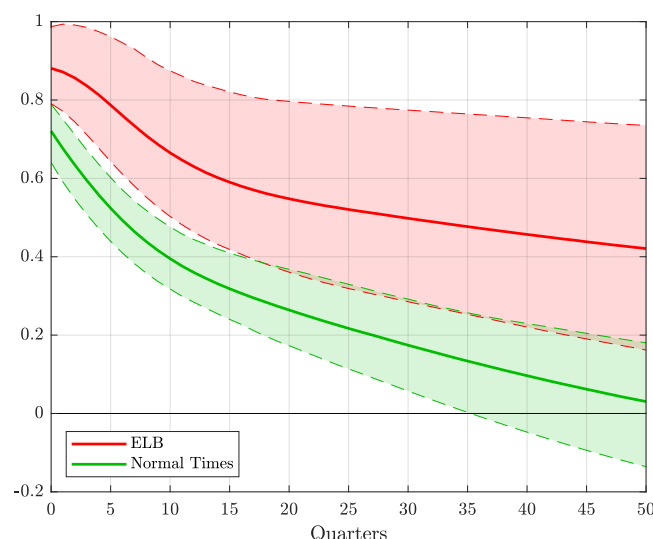
Figure 2 – Cumulative Government Consumption Multipliers: Normal Times vs ELB



Note: The dashed lines represent 99% bands capturing estimated parameter uncertainty. Solid lines represent the median of the simulations.

²⁵ I remove the first 5 periods of the simulation, before the government consumption shock is imposed, to create the IRF.

Figure 3 – Cumulative Government Consumption: Lagged Actual Interest Rate



Note: The dashed lines represent 99% bands capturing estimated parameter uncertainty. Solid lines represent the median of the simulations.

The general shape of the cumulative government consumption multipliers is similar for all interest rate assumptions. Cumulative government consumption multipliers are highest on impact and decline over time as the tax rate on labour income, which is distortionary, is increased to pay down government debt, which has initially increased to finance government consumption. Government consumption multipliers are larger at the endogenously binding lower bound, under both shadow rate assumptions, than in normal times, although they do not exceed 1. This contrasts with the results in Leeper et al. (2011). Using prior predictive analysis with a similar model, Leeper et al. (2011) find a large proportion of government consumption multipliers greater than 1 on impact. In Section 7 I use Monte Carlo filtering to understand which features of the model contribute to larger government consumption multipliers. I also re-calculate some of the multipliers by changing a subset of the parameters that contribute to larger multipliers as identified by the Monte Carlo filtering exercise.

Figures 2 and 3 show government consumption multipliers are larger at the lower bound when the shadow rate is a function of the lagged actual interest rate, with some of the parameter draws getting very close to 1.²⁶ As discussed earlier the shorter expected duration of the lower bound provides less monetary support as by-gones are by-gones at the lower bound when the shadow rate is a function of the lagged actual interest rate. After the economy exits the lower bound, monetary policy does not directly respond to events that occurred at the lower bound. This means demand shocks, including government consumption shocks, have a larger impact at the lower bound. This lack of history dependence in the shadow interest rate rule contributes to larger government consumption multipliers at the lower bound. History dependent monetary policy has been shown to have good stabilisation properties in forward looking models, which would moderate both the positive and negative impact of demand shocks, including government spending shocks. This finding is also consistent with Christiano et al.'s (2011) observation that more costly recessions are likely to lead to larger government spending multipliers.²⁷

²⁶ This result highlights the importance of accounting for parameter uncertainty in the analysis.

²⁷ As noted earlier, for the same sequence of negative demand shocks, the recession is deeper when the shadow rate is a function of the lagged actual interest rate.

In a relatively simple New Keynesian DSGE model, Hills & Nakata (2018) find government expenditure multipliers that exceed 1 when the shadow rate lacks a smoothing term, or is a function of the lagged actual interest rate. The shadow interest rate will only respond to current economic conditions when it lacks a smoothing term, which is also the case when the smoothing term in the shadow interest rate is the lagged actual interest rate. They find multipliers smaller than 1 when the shadow interest rate is a function of the lagged shadow rate. While I am unable to replicate Hills & Nakata's (2018) results exactly using my larger more complicated model, the general direction of my result is consistent with theirs, namely that making the shadow interest rate a function of the lagged actual interest rate raises government spending multipliers.

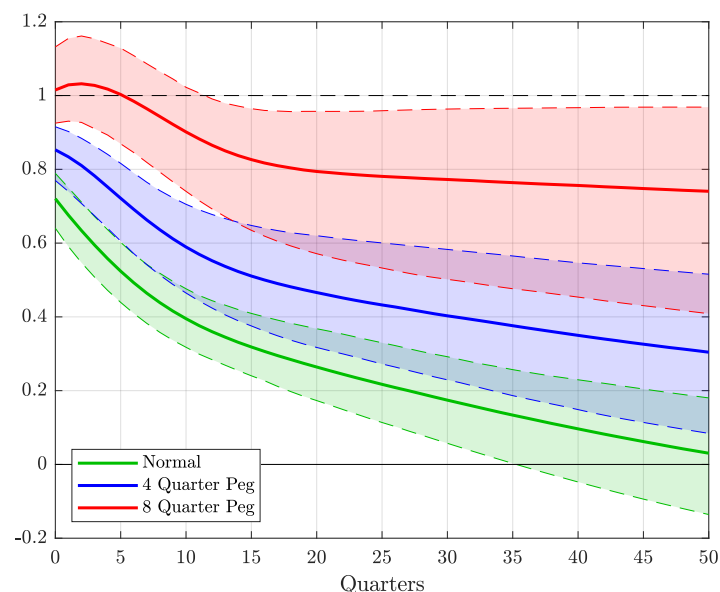
At first glance, it may seem advantageous to make smoothing in the shadow rate rule a function of the lagged actual interest rate, in order to increase the size of government consumption multipliers. However, this view ignores the wider implications of this policy choice on the economy. Under this shadow rate assumption, recessions are potentially worse, with GDP and inflation falling by more and taking longer to return to steady state. The lack of history dependence at the lower bound and in the periods after exiting the lower bound are likely to lead to poorer stabilisation properties and more volatility in general.

As mentioned in Section 2.3, the timing of historical personal income tax changes and the detrending method used may overstate the estimated response of labour tax revenues to the business cycle and the role automatic stabilisers play in the model. I investigate this by adjusting the response of the labour income tax rate to the output gap to better match the sensitivity to the business cycle based on OECD calculations. In particular, I reduce the output gap response in the labour tax rate rule, ψ_ℓ to 0.25 from 1.94 so that the response of labour tax revenue is less sensitive to the output gap and closer to OECD estimates for New Zealand (see Price et al. 2015, for OECD estimates of the elasticity of personal income with respect to the output gap). I recalculate all the cumulative multipliers and plot them in Figure 15 in Appendix D. Reducing the role of automatic stabilisers through labour taxes increases the size of government consumption multipliers, but the increases are small.

5.2 Monetary Policy With Pegged Interest Rates

I plot the cumulative government consumption multipliers when interest rates are pegged for 4 and 8 quarters against the multipliers in normal times in Figure 4 below.

Figure 4 – Cumulative Government Consumption Multipliers: Interest Rate Peg



Note: The dashed lines represent 99% bands capturing estimated parameter uncertainty. Solid lines represent the median of the simulations.

When the interest rate is pegged for 4 quarters the government consumption multiplier is larger than it is in normal times, but still smaller than 1. However, when the interest rate is pegged for 8 quarters, the median government consumption multiplier exceeds 1 for a number of quarters. Coenen et al. (2012) also find government consumption multipliers increase with the expected duration of the lower bound and can exceed 1 when monetary policy is accommodative for two or more years.²⁸ This demonstrates the power of (calendar-based) Odyssean forward guidance. An increase in government consumption in the model can result in median multipliers greater than 1 for a period of 5 quarters, if the central bank can credibly commit to keeping interest rates at the lower bound for two or more years, independent of economic conditions.

5.3 Comparing the Interest Rate Peg with the Endogenously Binding Lower Bound

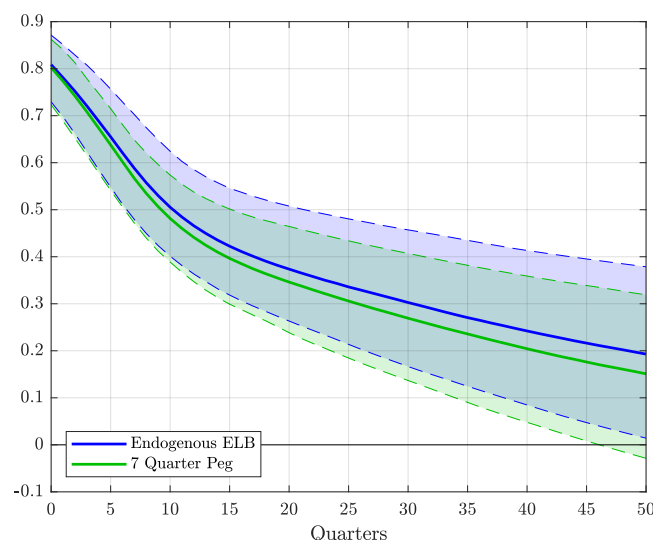
In order to understand how the method of imposing the lower bound affects the results, I run some additional simulations that compare government consumption multipliers calculated under an interest peg with government consumption multipliers calculated when the lower bound is endogenously binding. To improve comparability, I re-calculate government consumption multipliers under an interest rate peg that matches the median duration of the endogenously binding lower bound after the government consumption shock occurs. I also set the interest rate in the period(s) after the economy exits the interest rate peg using the same shadow rate rule used with the endogenously binding lower bound to ensure a fair comparison of the results.

I start with the government consumption multiplier calculated at the endogenously binding lower bound when the shadow rate is a function of the lagged shadow rate. In the median case, the government consumption shock is supported by interest rates that remain at the

²⁸ More generally Leeper et al. (2017) finds that government consumption multipliers increase with the expected duration at the lower bound.

lower bound for 7 quarters.²⁹ For comparability, I re-calculate the government consumption multiplier under a 7 quarter interest rate peg and I assume that when the economy exits the peg, the monetary authority sets interest rates according to a rule where smoothing is captured by the lagged shadow rate.³⁰ I plot the cumulative government consumption multipliers under both interest rate assumptions in Figure 5 below.

Figure 5 – Cumulative Government Consumption Multipliers: 7 Quarter Interest Rate Peg vs Endogenous ELB



Note: The dashed lines represent 99% bands capturing estimated parameter uncertainty. Solid lines represent the median of the simulations. The shadow interest rate is a function of the lagged shadow interest rate.

The results calculated under the two interest rate assumptions are remarkably similar, with the medians almost coinciding for the first 5 to 10 quarters after the shock. At 50 quarters there is a little more separation between the results, although they remain quite close. It should be noted that the 99% band for the cumulative multipliers calculated at the endogenously binding lower bound contains model draws with both shorter and longer durations at the lower bound than the median, with lower bound durations ranging from 5 to 10 quarters. Even with the variation in the duration of the lower bound in the endogenously binding case, the results are remarkably similar.

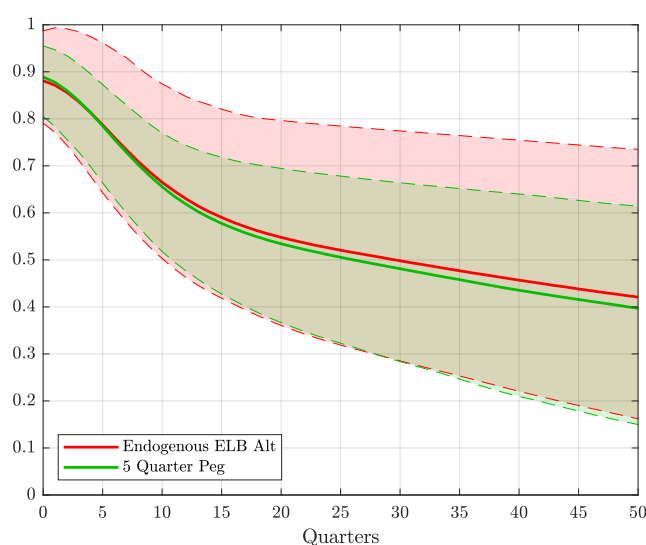
To complete the comparison, I compare (i) government consumption multipliers calculated at the endogenously binding lower bound when the shadow rate is a function of the lagged actual interest rate with (ii) multipliers calculated under an interest rate peg. In the median case, monetary policy provides 5 quarters of accommodation at the endogenously binding lower bound, following the government consumption shock. I re-calculate government consumption multipliers under a 5 quarter interest rate peg and I assume that the monetary authority sets interest rates according to a Taylor rule that is a function of the lagged actual interest rate, when they exit the interest rate peg.³¹ The results from these simulations are plotted in Figure 6 below.

²⁹ The median duration at the lower bound is 8 quarters and the government consumption shock occurs in the second period at the lower bound.

³⁰ This differs from the assumptions made in equation (5) and used earlier in this section to calculate multipliers under an interest rate peg.

³¹ This is the same assumption made in equation (5) and used to calculate government consumption multipliers under an interest rate peg earlier in this section.

Figure 6 – Cumulative Government Consumption Multipliers: 5 Quarter Interest Rate Peg vs Endogenous ELB



Note: The dashed lines represent 99% bands capturing estimated parameter uncertainty. Solid lines represent the median of the simulations. The shadow interest rate is a function of the lagged actual interest rate.

Again median cumulative government consumption multipliers are almost identical under the two monetary policy assumptions. However, the upper bound of the multipliers' Bayesian credibility interval is higher when the lower bound is endogenously binding. This reflects the variable support fiscal policy gets from monetary policy due to the variation in the lower bound durations. Monetary policy keeps rates at the lower bound between 4 and 8 quarters after the government consumption shock when the lower bound is endogenously binding, with the upper tail driven by lower bound durations that are longer than the median.

Figures 5 and 6 highlight the combined role the duration at the lower bound and the assumptions about the shadow rate play in calculating government consumption multipliers. All else equal, if interest rates are expected to remain unchanged for the same period of time, and the shadow rate is determined in the same way, then government consumption multipliers are going to be very similar, regardless of whether the interest rate is pegged or endogenously constrained by the lower bound. This means multipliers calculated under an interest rate peg can be used to proxy for multipliers calculated under an endogenously binding lower bound, if the goal is to understand how the expected duration of the interest rate constraint affects the size of multipliers. However, if the goal is to understand the factors that determine the duration of the lower bound and the role that fiscal policy plays in the decision to exit the lower bound, then multipliers should be calculated at the endogenously binding lower bound. Erceg & Lindé (2014) investigate how the size of fiscal stimulus affects both average and marginal fiscal multipliers when the lower bound is endogenously binding and increased fiscal stimulus can hasten the exit from the lower bound.

5.4 Comparing Results With the Recent Estimates for New Zealand

I summarise my estimated government consumption multiplier results in Table 1. I include recent VAR estimates for New Zealand as a comparison.

Table 1 – Government Consumption Multipliers: Comparing the DSGE with Recent Estimates for New Zealand

Study	Monetary Policy	Model	Impact	1-Year	2-Years	3-Years	4-Years	5-Years
	ELB Lagged Shadow Rate	DSGE	0.81	0.72	0.59	0.48	0.42	0.38
	ELB Lagged Actual Rate	DSGE	0.88	0.84	0.73	0.65	0.59	0.55
	4 Quarter Peg	DSGE	0.86	0.78	0.66	0.57	0.51	0.47
	8 Quarter Peg	DSGE	1.02	1.03	0.96	0.88	0.83	0.80
	Normal times	DSGE	0.72	0.59	0.46	0.38	0.32	0.27
H & P (2022)	Linear (Normal times)	VAR	0.50	0.34	–0.17	0.02		
Lyu (2021)	Normal times	VAR		0.40	0.30	0.10	–0.40	–1.00
H-A & W (2018)	Normal times	VAR	0.59	0.82				
P & V (2014)*	Normal times	VAR	0.26	0.42				

Key: H & P (2022) = Haug & Power (2022)
H-A & W (2018) = Hamer-Adams & Wong (2018)
P & V (2014) = Parkyn & Vehbi (2014).

The estimated cumulative government consumption multipliers from the DSGE model, measured on impact, are larger than recent VAR estimates for New Zealand, when evaluated at their respective peaks. Typically the cumulative DSGE multipliers are largest on impact, but decay with time. By contrast, multipliers from the VAR models can be smaller on impact, peaking after a number of quarters. One year after the government consumption shock, the gap between the DSGE estimates and the VAR models narrows. The government consumption multiplier for the DSGE model is 0.72 on impact in normal times. The cumulative multipliers from Lyu (2021) rapidly decline before turning negative at the 4 year horizon. However, when uncertainty bands are factored in, both models overlap at these horizons. In Haug & Power (2022) multipliers peak on impact at 0.5 before falling away, turning negative over time. Hamer-Adams & Wong (2018) find government consumption multipliers of 0.59 on impact, increasing to 0.82 after 1 year. This is the only VAR model to have a peak multiplier that exceeds the DSGE model in normal times. Parkyn & Vehbi (2014), using a measure of government spending that combines both government consumption and government investment, find a multiplier of 0.26 on impact, increasing to 0.42 after 1 year. In a survey of the fiscal multipliers literature, Ramey (2019) finds peak cumulative government spending multipliers typically lie within the region of 0.6 to 1. The DSGE result is consistent with this result, although some of the VAR evidence is not.

Differences between the DSGE and VAR estimates can be explained in part by differences in these methodologies. VAR models impose fewer restrictions on the data, allowing “the data to speak”. However, short sample sizes usually restrict the number of variables that can be included in these models. Restrictions, like the GDP expenditure identity and the government’s intertemporal budget constraint, are not typically imposed on the model’s dynamics.³² This may mean the transversality conditions fail to hold and there are inconsistencies in the models’ predictions. By contrast, fiscal policy in monetary-fiscal DSGE models is subject to the government’s intertemporal budget constraint and identities like the expenditure definition of GDP must hold at all times. However, the high degree of internal consistency in DSGE models comes at a cost. DSGE models impose a large number of assumptions on the data generating process, some of which are more reasonable than others, that affect the model’s behaviour and the results.

³² While Parkyn & Vehbi (2014) includes a model consistent measure of government debt in their model, the intertemporal government budget constraint is not formally imposed on the model’s dynamics. Chung & Leeper (2007) is an exception, they impose the government budget constraint on the model’s dynamics as part of the estimation process.

6. Prior Predictive Analysis

In this section I present results from a prior predictive analysis (PPA) exercise. PPA is a type of specification analysis that quantifies the implications of both the model and prior specification for a given model behaviour, property or output. It involves taking a large number of parameter draws from the model's prior parameter distributions and calculating the model property of interest for each parameter draw. PPA has been used by Leeper et al. (2011) and Leeper et al. (2017) among others to understand the range of government consumption multipliers that a relatively standard monetary-fiscal DSGE model can produce.³³ PPA is a useful tool for both model builders and users to understand whether particular results generated by an estimated model are “baked-in” due to key modelling assumptions or prior parameter choices. It allows modellers to understand the range of results that should be expected from the estimated model and which results are ruled in or out, before the model is taken to the data.³⁴ In general estimation is expected to narrow the range of results produced by PPA.

I use PPA to investigate the range of government consumption multipliers that should be expected under the four monetary policy assumptions mentioned in Section 4. I plot the PPA multiplier bands against the corresponding estimated government consumption multipliers to understand how estimation changes the bands' shape. PPA bands are constructed by randomly drawing parameters from their prior distributions and calculating the cumulative government consumption multipliers for each parameter draw in the same way the estimated government consumption multipliers are constructed, I use 2000 draws to produce the PPA bands.³⁵

6.1 Government Consumption Multipliers in Normal Times

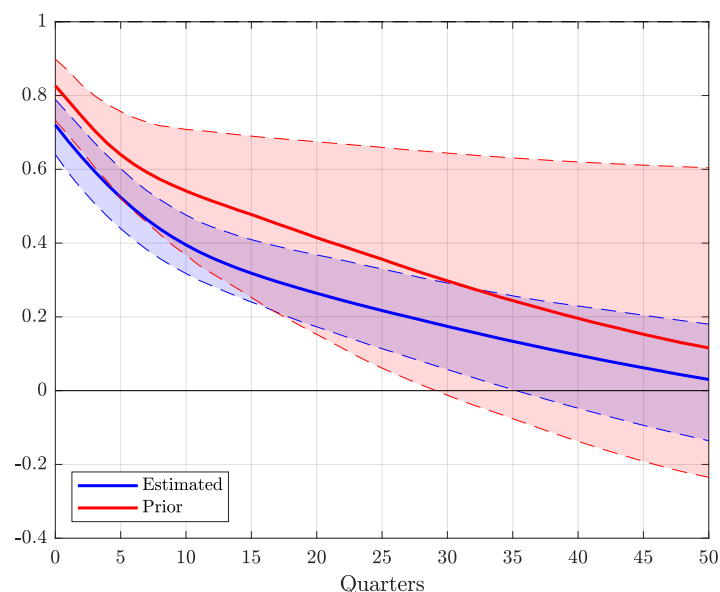
The PPA bands for the cumulative government consumption multipliers in normal times are plotted against the estimated bands in Figure 7 below.

³³ Geweke (2010) provides a textbook treatment of PPA.

³⁴ For example, if prior predictive analysis does not support multipliers larger than 1, estimation should not be expected to support them either.

³⁵ A more detailed mathematical description of the procedure can be found in Leeper et al. (2017).

Figure 7 – PPA: Government Consumption Multipliers in Normal Times



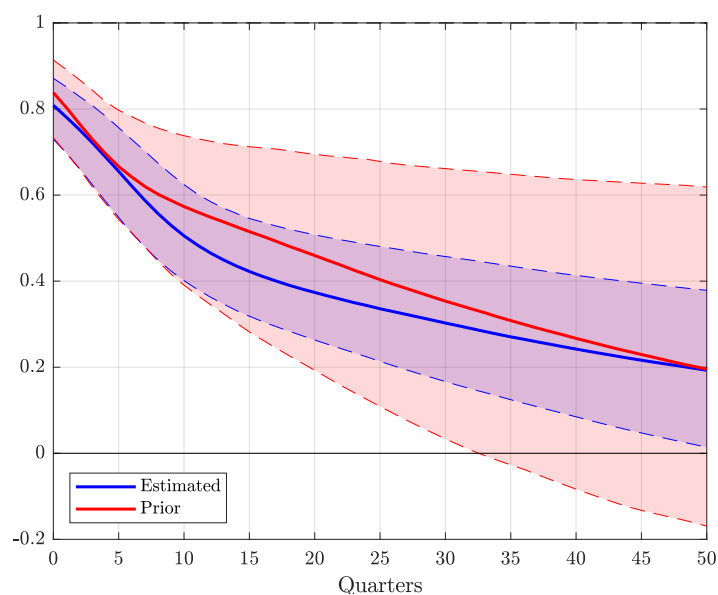
Note: The dashed lines represent 99% bands capturing estimated parameter uncertainty. Solid lines represent the median of the simulations.

The PPA multiplier bands are wider than the estimated bands, indicating that the data is informative and that estimation narrows the range of possible government consumption multipliers. This is consistent with the findings of Leeper et al. (2011). In fact the overall shape of both the estimated and the PPA bands in this paper is consistent with Leeper et al. (2011), although the impact multipliers for New Zealand calculated in this paper using the prior and the posterior are lower than Leeper et al.'s (2011) reflecting the larger import component in both government consumption and the other expenditure components of GDP. The estimated bands are also lower than the PPA bands, partially falling outside the lower edge of the 99% highest prior density interval. This demonstrates that when the data is sufficiently informative, it can pull parameters into regions with low prior support. I compare the parameter regions in the estimated model that generate multipliers outside the 99% PPA bands with the estimated parameters that generate multipliers inside the 99% PPA bands to understand which parameters are driving this result. The comparison of the parameter distributions is presented in Section G in the online appendix. They reveal that it is mainly the persistence of the government consumption process that is responsible for this result. The estimated process for government consumption is more persistent than the prior, falling in a region with extremely low prior mass. More persistent government consumption has larger negative wealth effects, as labour taxes, which are distortionary, are required to be elevated for longer in order to return government debt to target. In response, private consumption is lower and so is output.

6.2 Government Consumption Multipliers When the SSR Depends on the Lagged Shadow Rate

I plot the PPA bands for the government consumption multipliers at the endogenously binding lower bound when the shadow rate is a function of the lagged shadow rate in Figure 8.

Figure 8 – PPA: Government Consumption Multipliers at the ELB, Lagged Shadow Rate



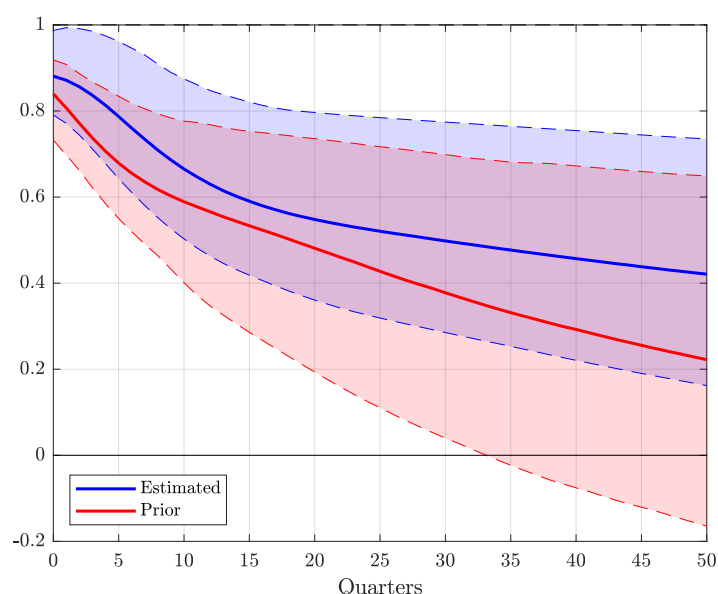
Note: The dashed lines represent 99% bands capturing estimated parameter uncertainty. Solid lines represent the median of the simulations.

As was the case for government consumption multipliers in normal times, estimation narrows the uncertainty bands around the multipliers. It also lowers government consumption multipliers relative to the prior, although they remain within the range implied by the PPA exercise.

6.3 Government Consumption Multipliers When the SSR Depends on the Lagged Actual Interest Rate

The PPA bands for government consumption multipliers when the shadow rate is a function of the lagged actual interest rate are plotted against the estimated bands in Figure 9.

Figure 9 – PPA: Government Consumption Multipliers at the ELB, Lagged Actual Interest Rate



Note: The dashed lines represent 99% bands capturing estimated parameter uncertainty. Solid lines represent the median of the simulations.

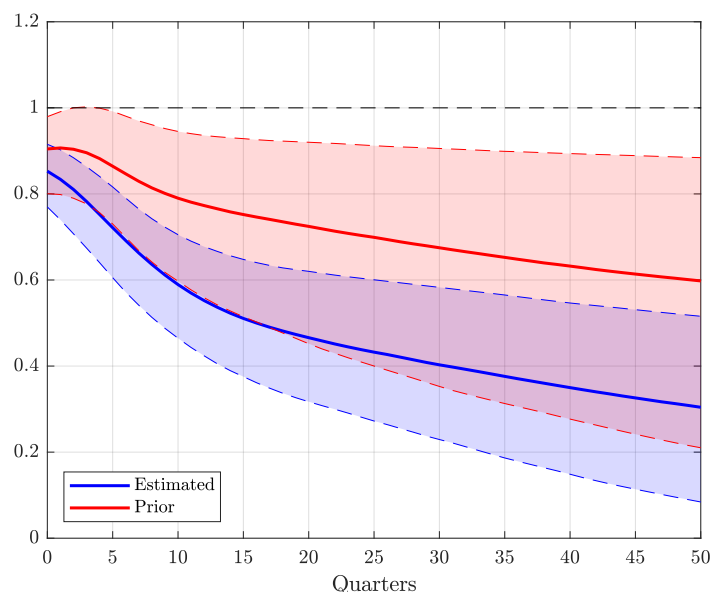
In this case the estimated bands, while slightly narrower, are higher relative to the PPA bands. Comparing the distributions of the estimated parameters that generate multipliers outside the 99% PPA bands with those that generate multipliers inside the PPA bands reveals that this is predominantly driven by the persistence of the risk premium shock.³⁶ The risk premium shock is the negative demand shock used to estimate the recession scenarios that in turn are used to produce the government consumption multipliers at the endogenously binding lower bound. More specifically, the estimated draws above the upper 99% PPA band are generated by more persistent risk premium shock processes that cause deeper recessions and more prolonged periods at the lower bound. This amplifies the GDP response to the government consumption shock, raising the multiplier. This result is also consistent with Christiano et al.'s (2011) observation that deeper recessions in conjunction with a binding lower bound on interest rates result in larger government spending multipliers.

6.4 Government Consumption Multipliers With an Interest Rate Peg

I plot the PPA bands against the estimated bands for government consumption multipliers under a four quarter interest rate peg in Figure 10 below.

³⁶ The parameter distributions are presented in Section G of the online appendix.

Figure 10 – PPA: Government Consumption Multipliers 4 Quarter Interest Rate Peg



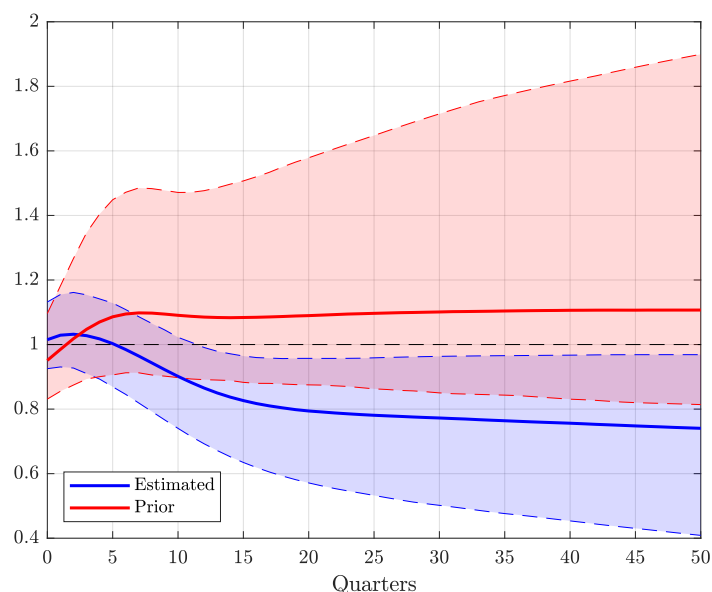
Note: The dashed lines represent 99% bands capturing estimated parameter uncertainty. Solid lines represent the median of the simulations.

As was the case in normal times, estimation narrows and lowers the multiplier bands for government consumption, with a substantial portion of the estimated distribution falling below the bottom 99% PPA band. This is mainly driven by a more persistent government consumption process, as was the case for lower estimated government consumption multipliers in normal times.³⁷ The estimated persistence parameter for government consumption falls outside the region with the most prior support.

The PPA bands for government consumption multipliers under an eight quarter interest rate peg are plotted against the corresponding estimated bands in Figure 11.

³⁷ See Section G of the online appendix for a comparison of the parameter distributions of the multipliers that fall within the 99% PPA bands and those that fall outside.

Figure 11 – PPA: Government Consumption Multipliers 8 Quarter Interest Rate Peg



Note: The dashed lines represent 99% bands capturing estimated parameter uncertainty. Solid lines represent the median of the simulations.

The story is the same for an eight quarter interest rate peg as it was in both normal times and for a four quarter interest rate peg. As in most of the other analysis, estimation narrows and lowers the bands, with more than half the draws falling below the region with the most prior support. Again, this is largely driven by the persistence of government consumption, which is higher and falls in a region with much lower prior support.

As highlighted by this exercise, the range of government consumption multipliers produced by the model and the prior is relatively large, although estimation helps narrow this range. Estimation lowers government consumption multipliers relative to the prior in all cases, except when the shadow rate is a function of the lagged actual interest rate. Estimation can also pull multipliers into regions with low prior support, demonstrating how the data can override the prior if it is sufficiently informative. Lower estimated multipliers are largely driven by a more persistent government consumption process than the prior supports. In the case where the shadow rate is a function of the lagged actual interest rate, estimated government consumption multipliers are pulled higher into regions with low prior support. These larger multipliers are primarily due to a more persistent risk premium shock process in relation to the prior support. A more persistent risk premium process, which is used to produce the recession scenarios, means deeper and more persistent recessions, resulting in a longer lower bound duration that is translated into larger government consumption multipliers.

7. Monte Carlo Filtering

Policymakers and their advisors want to know which factors determine the size of fiscal multipliers. This information can be used in the design and implementation of discretionary fiscal policy. Structural models provide a platform for investigating the determinants of fiscal multipliers. Structural models can be used for counterfactual analysis because they illustrate and incorporate changes in private decision rules when policy rules are amended. Parameter sensitivity analysis can be applied to structural models to determine which factors contribute to larger fiscal multipliers. This can be done locally by changing

parameters one at a time, although any results will be conditional on the values of the remaining parameters, which might not be particularly helpful when both the plausible range of parameter values and the number of parameters are large.

Monte Carlo filtering, first used in a DSGE modelling context by Ratto (2008), is a global parameter sensitivity tool that gets around this problem by calculating the marginal distribution of parameters consistent with a particular output, result or behaviour (larger government consumption multipliers in this case). Randomly sampling all parameters of interest from their respective parameter supports at the same time, and then focusing, one at a time, on the parameters that generate a particular result or behaviour, removes the influence of nuisance parameters. It is also possible to look at the pairwise plots of the parameter combinations that are both consistent and inconsistent with a behaviour, as these may capture meaningful parameter interdependencies. I do not report such results here, because the pairwise results are not particularly interesting or informative in this case. The set of parameters responsible for the behaviour of interest can be determined by comparing the univariate parameter distributions that generate the behaviour, with the parameter distributions that do not. Statistically significant differences between parameter distributions indicate that a parameter plays a role in generating the behaviour of interest.

The Monte Carlo filtering procedure involves the following steps:

1. I randomly sample 20,000 parameter draws for all estimated model parameters and a *subset* of the model's calibrated parameters, where I assume parameters are uniformly distributed over sensible parameter ranges. The remaining parameters are left fixed at their calibrated values, which are listed in Table 8. A full list of the parameters varied in the Monte Carlo filtering analysis and their respective supports can be found in Appendix C.
2. For each parameter draw, I calculate cumulative government consumption multipliers, using the approach from Sections 5 and 6.
3. I sort the government consumption multipliers by size, separating them into two groups, those with multipliers greater than or equal to the 10th percentile (the largest multipliers) and those with multipliers smaller than the 10th percentile (the smallest multipliers). I repeat this for both government consumption multipliers evaluated on impact and for cumulative multipliers evaluated two years after the shock.
4. Using a two sample Kolmogorov-Smirnov test, I test the null hypothesis that the parameter distributions that produce the largest multipliers are the same as those that produce the smaller multipliers.
5. For the parameters with distributions that are statistically different at the 1% level, I report parameter distributions and skewness statistics for the parameter draws that produce the largest government consumption multipliers.

Before going through the results, I make the following observation: because multipliers calculated under an exogenous interest rate peg are similar to multipliers calculated at the endogenously binding lower bound when both the expected duration of the lower bound and the shadow rate assumption are the same, differences in the Monte Carlo filtering results at the endogenously binding lower bound should reflect some of the factors that determine both entry and exit to the endogenously binding lower bound and the endogenously determined duration of the lower bound.

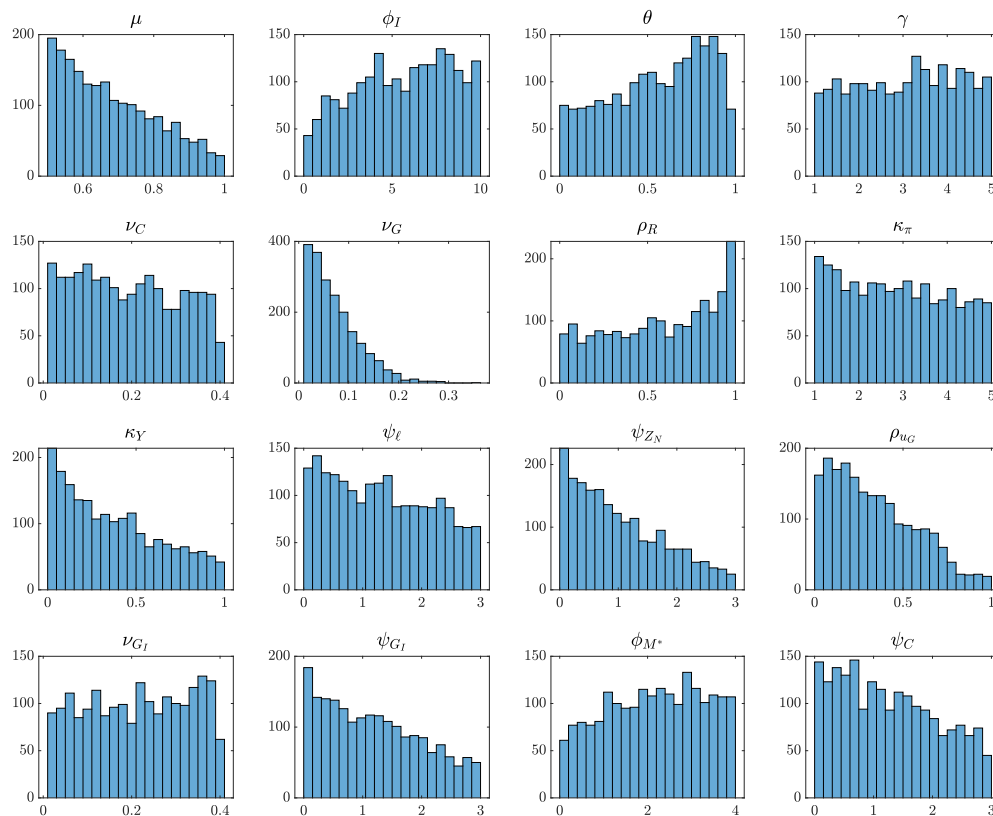
I run Monte Carlo filtering on 5 different monetary policy settings with cumulative multipliers evaluated at 2 different time horizons, resulting in 10 sets of Monte Carlo filtering results.

In total, 34 parameters are found to be important determinants of larger government consumption multipliers in the 10 sets of results.

I illustrate the results from the Monte Carlo filtering exercise for the largest government consumption multipliers on impact, when monetary policy is set according to a Taylor-type rule in normal times using histograms in Figure 12 below. The histograms for the Monte Carlo filtering exercises for the largest government consumption multipliers produced under the other monetary policy settings can be found in Section H in the online appendix.

I summarise the results from the Monte Carlo filtering analysis in Table 2, where I present the Pearson's skewness coefficient for the distributions with differences that are statistically significant for each policy setting and horizon. A negative number indicates the distribution is left skewed and that more mass is present in higher values of the parameter in question. Likewise, a positive coefficient indicates the distribution is right skewed and more mass is present in lower values of the parameter. I colour code the skewness coefficients, with blue indicating lower values of the parameter are consistent with higher multipliers and red indicating higher values of the parameter are more likely to lead to larger multipliers. Darker shades indicate a more skewed distribution and a more pronounced relationship.

Figure 12 – Monte Carlo Filtering: Parameter Distributions for the Largest Government Consumption Multipliers in Normal Times



The parameters presented in Figure 12 were drawn from uniform distributions. Their non-uniform shape reflects regions of the parameter space that are more consistent with larger government consumption multipliers and in some cases regions where the model cannot be solved. For this reason the two-sample Kolmogorov-Smirnov test is conducted on the parameter draws consistent with larger multipliers and the remaining parameter draws consistent with smaller multipliers, as both sets of parameter draws will cover regions where the model can be solved. I refrain from discussing the interpretation of these results at this point and summarise the results from all the Monte Carlo filtering exercises in Table

2, where I use Pearson's skewness coefficient to convey which regions of the parameter space are more likely to lead to larger multipliers. I have grouped the parameters by type in the table, and this is reflected in the discussion that follows.

Table 2 – Pearson's Skewness Coefficient: Parameter Regions With Larger Government Consumption Multipliers

Parameter	Normal Times		ELB Shadow Rate		ELB Actual Rate		4 Quarter Peg		8 Quarter Peg	
	Impact	2 years	Impact	2 years	Impact	2 years	Impact	2 years	Impact	2 years
Fiscal Policy										
ρ_{uG}	0.48	0.72	0.32	0.54	0.25	0.56	0.04	0.41	-0.75	-0.24
γ_ℓ		0.32	-0.20							
ψ_C	0.32	0.09	0.22	0.09	0.15	0.18	0.45	0.37	0.36	0.27
ψ_G						0.03			0.18	0.19
ψ_{G_I}	0.34	0.28	0.49	0.41	0.37	0.32	0.39	0.34	0.22	0.16
ψ_K		-0.10			-0.05					
ψ_ℓ	0.25		0.34	0.14	0.26		0.28	0.25	0.24	0.09
ψ_{Z_N}	0.67	0.40	0.61	0.26	0.62	0.20	0.72	0.66	0.49	0.36
Monetary Policy										
κ_π	0.11	0.11		0.22		0.24	0.23	0.77	0.08	0.15
κ_Y	0.53	0.81	0.41	0.57	0.32	0.15		-0.09		
ρ_R	-0.24	0.54		0.19	-0.15	-0.10	-0.17	-0.35	-0.18	-0.18
Preferences										
γ	-0.21	-0.26	-0.16	-0.12	-0.09					
θ	-0.36	-0.34	-0.47	-0.37	-0.36	-0.41	-0.10	-0.14	0.15	0.04
ξ		0.53							-0.11	-0.11
Price and Wage Rigidities										
ι_F			-0.03	0.10				0.18		
ι_H				0.13	0.00	0.15	-0.08		-0.48	-0.67
ι_W									-0.21	-0.49
ϕ_P				-0.15		-0.23	0.10	-0.16	0.37	0.15
ϕ_F					0.03				0.08	0.11
ϕ_W				-0.04			0.19	0.24	0.31	0.38
Final Good Production										
μ^*		0.20		0.10						-0.04
μ_C				0.01				0.10		0.08
μ_G			0.02							
μ_I					-0.06	-0.06				
ν_C	0.12	0.31		0.28		0.12	0.10	0.25		0.17
ν_G	0.74	0.75	0.93	0.61	0.92	0.69	0.83	0.91	0.79	0.37
ν_{G_I}	-0.11						-0.11			
ν_I									0.17	0.13
Miscellaneous										
μ	0.50	0.41	0.64	0.46	0.64	0.55	0.63	0.66	0.44	0.47
α_G			0.20						-0.16	-0.14
ϕ_I	-0.21	-0.47	-0.01	-0.21	0.10	-0.20	0.23	0.19	0.64	0.86
ϕ_X	-0.15			0.00		0.06			0.22	
ρ_{AB}			-0.59	-1.30	-0.56	-1.20				
χ									0.01	

Key: Blue indicates lower parameter values are more likely to generate larger government consumption multipliers. Red indicates higher parameter values are more likely to generate government consumption values. Darker shades indicate a more skewed distribution and a stronger relationship between the parameter and the size of the government consumption multiplier.

Fiscal Policy: The fiscal policy section of Table 2 is largely shaded in blue, indicating that weaker, less responsive and less persistent fiscal policy is more likely to lead to larger government consumption multipliers, across almost all monetary policy assumptions and horizons.

The persistence of government consumption shocks, ρ_{uG} , matters for the size of govern-

ment consumption multipliers. More persistent government consumption shocks result in smaller government consumption multipliers when monetary policy is set according to a Taylor-type rule in normal times, when the lower bound is endogenously binding and when the interest rate is pegged for 4 quarters. In the parameterisation of the model used in this paper, labour taxes are assumed to adjust to bring government debt back to target. Increases in government consumption create a negative wealth effect as labour taxes are expected to rise to pay down government debt, leading to a reduction in private consumption. More persistent government consumption shocks mean labour taxes have to remain elevated for longer resulting in a larger negative wealth effect and a larger reduction in private consumption.

The relationship between the size of government consumption multipliers and the persistence of government spending is also affected by the monetary policy regime. More specifically when the interest rate is pegged, or constrained by the lower bound, the persistence of the government consumption process that generates larger government consumption multipliers will be related to the length of time interest rates are expected to be fixed. As mentioned by Christiano et al. (2011), government spending should occur when interest rates are fixed and not beyond this period, in order to obtain larger government spending multipliers. The Monte Carlo filtering exercise with an 8 quarter interest rate peg reinforces this point. When interest rates are fixed for an extended period of time, more persistent government spending that stays above steady state for longer is converted into larger government consumption multipliers as a larger share of government spending occurs over the period monetary policy is accommodative.

Weaker automatic stabilisers, especially with regard to transfer payments, ψ_{Z_N} , government investment, ψ_{G_I} , labour income taxes, ψ_ℓ , and consumption taxes, ψ_C , are more likely to result in larger government consumption multipliers. These automatic policy responses work directly to offset deviations of output from trend, reducing government consumption multipliers. Batini et al. (2014) include weak or weaker automatic stabilisers as one of the conditions for larger fiscal multipliers.

Monetary Policy: The Monte Carlo filtering exercise provides evidence that government consumption multipliers are declining in the interest rate response to the output gap, κ_Y , and the inflation gap, κ_π . A stronger response to the output gap by monetary policy directly offsets the output response from the fiscal stimulus, reducing multipliers. A weaker response to inflation in the Taylor rule generates a stronger inflation response, which lowers the real interest rate, all else equal, resulting in larger government consumption multipliers. Christiano et al. (2011) find the same result in a simple closed economy New Keynesian DSGE model.

The interest rate smoothing parameter, ρ_R , also plays a role in determining the size of government consumption multipliers on impact, although the relationship is dependent on the monetary policy regime. Larger values of the interest rate smoothing parameter are consistent with larger multipliers on impact when monetary policy is set according to a Taylor type rule. As the smoothing parameter approaches 1, the nominal interest rate becomes a constant, equivalent to pegging the interest rate. The lack of movement in the nominal interest rate means fiscal stimulus that increases inflation and inflation expectations will be directly translated into a reduction in real interest rates.

When monetary policy is set according to a Taylor-type rule (ignoring the effective lower bound) and government consumption multipliers are evaluated two years after the shock, less persistent monetary policy is likely to lead to larger government consumption multipliers. This is because less persistent monetary policy indicates less history dependence and

weaker monetary policy in a macroeconomic demand stabilisation sense and a reduced response from monetary policy to a government consumption shock.

When the shadow rate is a function of the lagged actual interest rate and interest rates are pegged for 4 or 8 quarters, higher levels of interest rate smoothing are more likely to lead to larger government consumption multipliers. This is because interest rate smoothing in the periods after the economy has exited to the lower bound will not be related to history dependence, but will instead determine the speed with which interest rates return to steady state.³⁸ A more persistent interest rate process will take longer to return to steady state, providing additional monetary policy accommodation, generating larger government consumption multipliers.

Preferences: According to the Monte Carlo filtering analysis, larger values of the inverse of the intertemporal elasticity of substitution, γ , are more likely to be associated with larger government consumption multipliers when the interest rate is set according to a Taylor-type rule, or the shadow interest rate is a function of the lagged shadow rate when monetary policy is constrained by the lower bound. This is because larger values imply smoother consumption that is less sensitive to interest rate changes. As a consequence the monetary policy response to increased government consumption will have a smaller effect on private consumption, which falls less in response, leading to a larger increase in GDP. Larger values of γ are also consistent with a larger response in hours worked, as the labour supply increases in response to the negative wealth effect.

In most monetary policy settings, larger values of the weight on habit formation, θ , are associated with larger government consumption multipliers. This is because in most of the scenarios, government consumption multipliers are less than 1. Higher values of θ mean more persistent private consumption and less crowding out in response to government consumption shocks. When interest rates are pegged for 8 quarters, government consumption multipliers are more likely to be larger than 1, so smaller values of θ are more likely to generate larger government consumption multipliers as they may encourage more crowding in of private consumption in response to the government consumption shock.

Smaller values of the inverse of the Frisch elasticity of labour supply, ξ , are more likely to lead to larger government consumption multipliers, when policy is set according to a Taylor type rule and government consumption multipliers are evaluated two years after the government consumption shock. Smaller values of ξ imply a more elastic labour supply. Increases in government consumption induce a positive labour response due to the negative wealth effect that results from the expectation of higher future labour taxes. A more elastic labour supply means there is a larger labour supply response to the reduction in consumption, leading to a larger output response.

Price and Wage Rigidities: When interest rates are pegged for 4 or 8 quarters, less rigid prices and wages (smaller values of ϕ_P and ϕ_W) are more likely to lead to larger government consumption multipliers. This is because less rigidity means a larger inflationary response to government consumption shocks and when this is combined with a fixed nominal interest rate this is translated into lower real interest rates.

When the interest rate is pegged for 8 quarters, stronger wage and price indexation (higher values of ι_W and ι_P respectively) is more likely to be associated with larger government consumption multipliers. More indexation implies more persistent inflation expectations which remain elevated for longer after a government consumption shock. This in turn is

³⁸ The interest rate in the period after exiting the peg will be a function of the pegged interest rate, rather than the shadow interest rate. As a result interest rate smoothing will not capture history dependence.

translated into a more persistent real interest rate response when the nominal interest rate is fixed.

Final Good Production: A smaller share of imports (represented by the foreign bias parameter, ν_G) in the production of government consumption is more likely to lead to larger government consumption multipliers irrespective of monetary policy settings. Imported government consumption is a leakage that does not directly support domestic production and activity. In many of the Monte Carlo filtering exercises, a smaller share of imported goods in private consumption (measured by the foreign bias parameter, ν_C) was also more likely to lead to larger government consumption multipliers. This is because imports are a leakage and if consumption is being crowded in, some of this will be spent on imports, which won't directly provide support to the domestic economy.

Miscellaneous: The Monte Carlo filtering exercise shows, regardless of monetary policy settings, larger government consumption multipliers are more likely to be associated with a smaller share of Ricardian households, μ . Government consumption raises output through a negative wealth effect that makes households more willing to work. In the model, the rule of thumb household's labour decision is identical to that of the Ricardian household. As they are unable to save, the additional labour income received by the rule of thumb household is spent on consumption. A larger share of rule of thumb households (or alternatively a smaller share of Ricardian households) means rule of thumb consumption makes up a greater share of total consumption, providing a larger offset to the fall in Ricardian consumption due to the negative wealth effect. This is translated into a larger increase in GDP.

Government consumption multipliers are more likely to be larger for larger values of the weight on investment adjustment costs, ϕ_I when monetary policy is set according to a Taylor-type rule or the economy is constrained by the endogenously binding lower bound on interest rates. Under these monetary policy settings, government consumption multipliers are still more likely to be less than 1, so that more investment rigidity means less crowding out of private sector activity leading to larger government consumption multipliers. When the interest rate is pegged for 4 or 8 quarters, smaller values of ϕ_I are more likely to lead to larger government consumption multipliers. This is because government consumption multipliers are more likely to be larger than 1 and more flexible investment means more investment is crowded in by government spending.

Larger values of ρ_{AB} , which governs the persistence of the risk premium shock process, are more likely to lead to larger government consumption multipliers at the endogenously binding lower bound. The risk premium shock is used to create the recession scenarios when the lower bound is endogenously binding and a more persistent risk premium shock process is more likely to lead to larger and more persistent recessions. Larger and more persistent recessions lead to a longer expected duration at the lower bound, which amplifies demand shocks, including the government consumption shock. This is consistent with the observation made by Christiano et al. (2011), that more costly recessions lead to larger government spending multipliers.

7.1 Further Sensitivity Testing

The Monte Carlo filtering analysis highlights a number of parameters that are associated with larger government consumption multipliers. I investigate alternative parameterisations of the model to examine the implications of,

- Trade openness,
- The persistence of the government consumption shock,

- The strength of automatic stabilisers,
- Habit persistence in consumption,

on the size of government consumption multipliers. I re-calculate government consumption multipliers in both normal times and at the endogenously binding lower bound where the shadow rate is a function of the lagged shadow rate. The re-parameterisations are listed in Table 3, where all remaining parameters are set at their estimated or previously calibrated levels. The cumulative government consumption multipliers are presented in Figure 13.

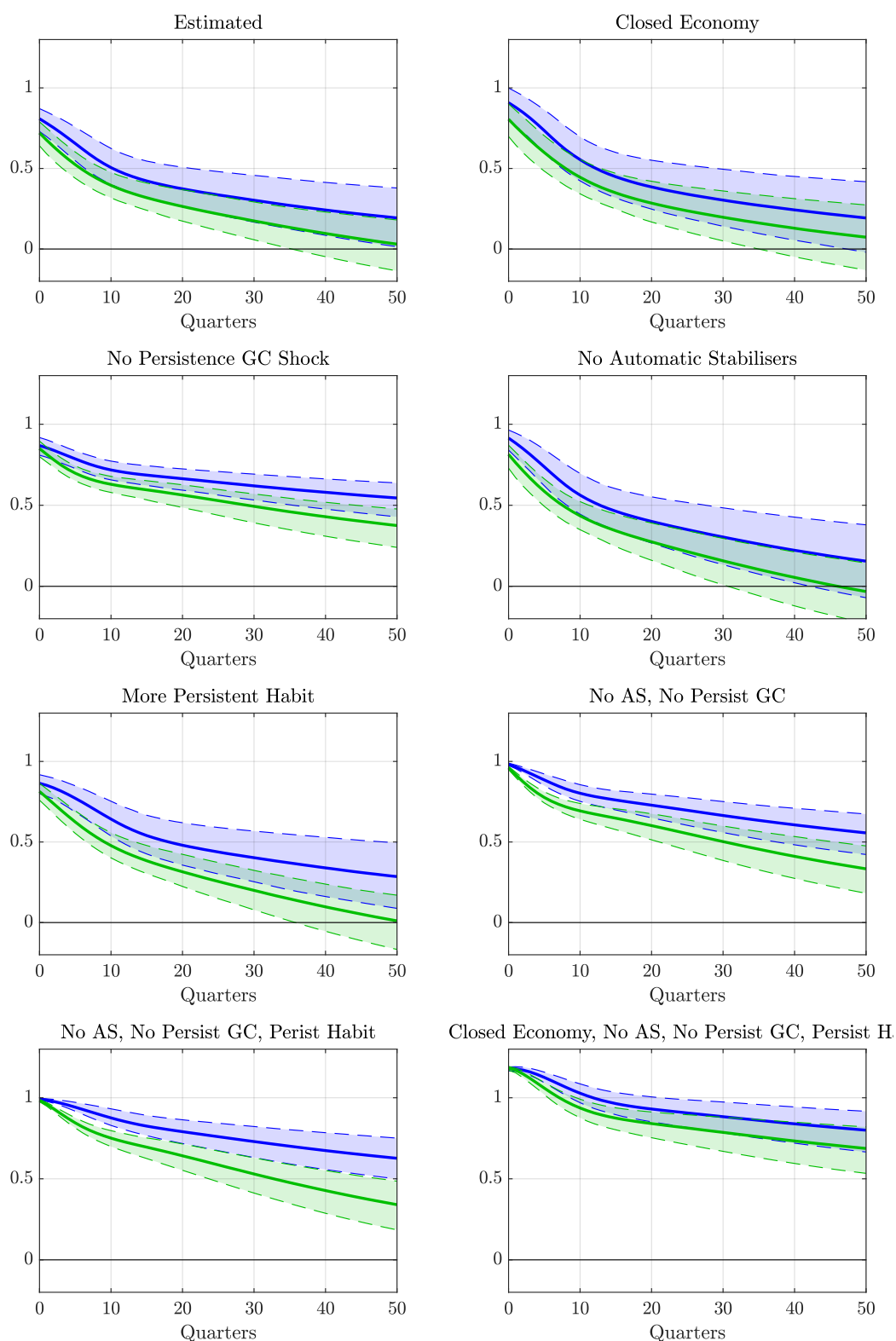
Table 3 – Sensitivity Testing

Chart Name	Description	Chart Location	Parameter Changes
Closed Economy	Import bias parameters are reduced to almost zero	Top row, right	$\nu_C, \nu_I = 0.00001$, $\nu_G, \nu_{G_I} = 0$
No Persistence GC Shock	Persistence in the government consumption shock is set to zero	Second row, left	$\rho_{u_G} = 0$
No Automatic Stabilisers	Weights in the output gap term in the fiscal rules set to zero	Second row, right	$\varphi_\ell, \varphi_K, \varphi_G, \varphi_{G_I}, \varphi_{Z_N}$, $\varphi_{Z_S} = 0$
More Persistent Habit	Habit persistence term increased	Third row, left	$\theta = 0.9$
No AS, No Persist GC	No automatic stabilisers and no persistence in the government consumption shock	Third row, right	$\varphi_\ell, \varphi_K, \varphi_G, \varphi_{G_I}, \varphi_{Z_N}$, $\varphi_{Z_S} = 0$, $\rho_{u_G} = 0$
No AS, No Persist GC, Persist Habit	No automatic stabilisers, no persistence in the government consumption shock, increased habit persistence	Bottom row, left	$\varphi_\ell, \varphi_K, \varphi_G, \varphi_{G_I}, \varphi_{Z_N}$, $\varphi_{Z_S} = 0$, $\rho_{u_G} = 0$, $\theta = 0.9$
Closed Economy, No AS, No Persist GC, Persist Habit	Closed economy, no automatic stabilisers, no persistence in the government consumption shock, increased habit persistence	Bottom row, right	$\varphi_\ell, \varphi_K, \varphi_G, \varphi_{G_I}, \varphi_{Z_N}$, $\varphi_{Z_S} = 0$, $\rho_{u_G} = 0$, $\theta = 0.95, \nu_C, \nu_I = 0.00001$, $\nu_G, \nu_{G_I} = 0$

Note that ν_C and ν_I are set to 0.00001 rather than 0. This is due to the way that foreign GDP is solved in the steady state.

AS = Automatic stabilisers, GC = Government consumption.

**Figure 13 – Counterfactual Government Consumption Multipliers:
Normal Times and Endogenously Binding Lower Bound**



Blue = Cumulative government consumption multipliers calculated at the endogenously binding lower bound, where the shadow rate is a function of the lagged shadow rate. Green = Cumulative government consumption multipliers calculated in normal times. All bands are 99% Bayesian credible intervals.

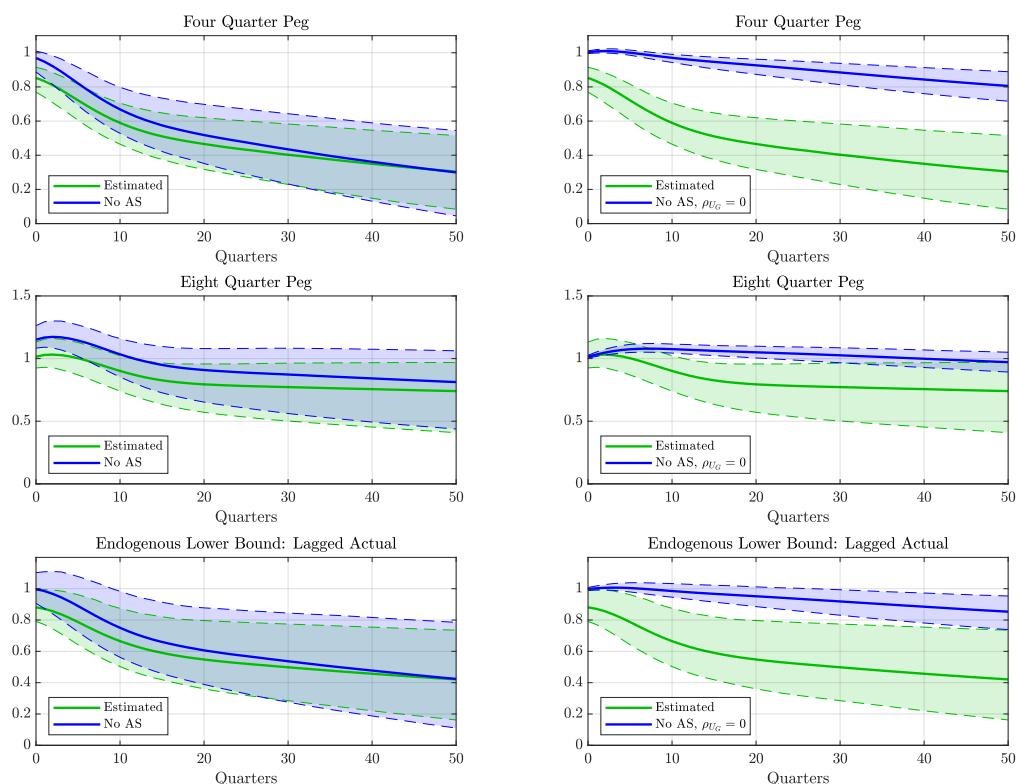
Re-calculating government consumption multipliers under the closed economy assumption

raises the median impact multiplier to 0.81 from 0.72 in normal times and to 0.91 from 0.81 at the endogenously binding lower bound. Government consumption shocks that are entirely transitory raise the impact multiplier to 0.85 in normal times and 0.87 at the endogenously binding lower bound. Likewise, switching off the automatic stabilisers raises the impact multiplier to 0.81 in normal times and 0.91 at the endogenously binding lower bound, while increasing habit persistence to 0.9 increases the impact multipliers to 0.81 in normal times and 0.86 at the endogenously binding lower bound.

Individually these are relatively small increases in the impact multiplier, however, when they are combined they result in impact multipliers that are substantially larger than 1, coming in at 1.18 when calculated in both normal times and at the endogenously binding lower bound. Leeper et al. (2017) calculate government spending multipliers in a closed economy model with a high level of habit persistence and no automatic stabilisers, and finds multipliers that are larger than 1 in normal times. Changing these parameters gets results that are more similar to Leeper et al. (2017) and helps explain why multipliers are smaller here in this open economy paper.

I investigate how automatic stabilisers and the persistence of the government consumption process affect government consumption multipliers calculated under pegged interest rates and at the endogenously binding lower bound where the shadow rate is a function of the lagged actual interest rate. The results from this exercise are plotted in Figure 14. The left column of Figure 14 contains government consumption multipliers calculated with automatic stabilisers switched off. The right column presents the government consumption multipliers with automatic stabilisers switched off and no persistence in the government consumption shock process.

**Figure 14 – Counterfactual Government Consumption Multipliers:
The Lower Bound and Pegged Interest Rates**



Note: The dashed lines represent 99% bands capturing estimated parameter uncertainty. Solid lines represent the median of the simulations.

It is clear from Figure 14 that automatic stabilisers reduce the size of discretionary government consumption multipliers. More persistent government consumption shocks amplify the reduction in the multiplier. In all cases presented government consumption multipliers are larger than 1 when automatic stabilisers are switched off and government consumption shocks are entirely transitory.

8. Large Government Consumption Multipliers and Macroeconomic Stabilisation

The Monte Carlo filtering analysis identified a number of factors that are associated with larger government consumption multipliers. These factors amplify the effects of the government consumption shock by affecting the channels through which government spending operates and the private sector's response to the shock. Some of these factors also amplify other demand shocks in the model, creating problems for macroeconomic stabilisation policy. In this section I conduct a series of simulation exercises to better understand how some of the factors associated with larger government consumption multipliers affect the mean and volatility of both GDP and inflation.

While the Monte Carlo filtering exercise identified a multitude of factors that affect multipliers under different monetary policy settings, I focus attention on a subset that were important across exercises. In particular, I look at how the volatility and the mean of both GDP and inflation are affected by,

- switching off automatic stabilisers,
- weaker monetary policy responses to deviations of inflation and output from their respective targets,
- a binding lower bound constraint,
- the share of Ricardian households,
- the persistence of the risk premium shock,
- and the openness of the economy.

Some of these are factors that a policymaker can influence, like monetary and fiscal policy settings. Some of these are features that are more difficult for policy to influence, but may have implications for determining the appropriate mix between using discretionary fiscal policy and allowing automatic fiscal stabilisers to operate.

The persistence of the risk premium shock appears in the list of factors that affect the size of government consumption multipliers because this shock is used to create the recession scenarios that induce the lower bound to bind endogenously. The persistence of the risk premium shock has direct implications for the duration of the recession and the length of time the lower bound is expected to bind.

I use a series of simulation exercises to determine the impact of the factors listed on the mean and volatility of GDP and inflation. More specifically, I simulate the model for 1000 periods, using the extended path algorithm with model parameter values set at the posterior mode, by feeding in sequences of independent and identically distributed random normal shocks. This forms my baseline simulation, which I compare my counterfactual simulations against. I then change the model parameters, one at a time, to create models matching the listed features and simulate the model again for 1000 periods using the same sequence of shocks from the baseline simulation. These are my counterfactual simulations. I discard the first 500 periods of each simulation to remove the influence of the initial condition and calculate first and second moments using the simulated data. In

total, I run 12 counterfactual simulations to understand how the features listed affect the overall volatility. The parameter and equation assumptions for each of the simulations are listed in Table 4 below. I only impose the lower bound constraint in the simulations where I want to measure the effects of the lower bound on the volatility of GDP and inflation. In all other simulations I assume that monetary policy is set according to a Taylor-type rule at all points in time and that interest rates can go below the effective lower bound. I also switch off the monetary policy shock in all simulations. I report the counterfactual results relative to the baseline in Table 5.

Table 4 – Simulation Parameter Assumptions

Counterfactual Model Assumptions	Parameter Changes/Equation Changes
<i>Automatic Stabilisers</i>	
No Automatic Stabilisers	$\psi_G = \psi_{G_I} = \psi_{Z_N} = \psi_{Z_S} = \psi_K = \psi_\ell = \psi_C = 0$
<i>Monetary Policy Response</i>	
Weaker Monetary Pol. Response to Inflation	$\kappa_\pi = 1.0001$
Weaker Monetary Pol. Response to Output Gap	$\kappa_Y = 0$
<i>Endogenously Binding ELB</i>	
Lagged Shadow Rate	$R_t^* = (R_{t-1}^*)^{\rho_R} \left(R \left(\frac{\pi_t}{\pi} \right)^{\kappa_\pi} \left(\frac{Y_t}{Y} \right)^{\kappa_Y} \right)^{1-\rho_R} \exp(\varepsilon_{R,t})$
Lagged Actual Rate	$R_t^* = R_{t-1}^{\rho_R} \left(R \left(\frac{\pi_t}{\pi} \right)^{\kappa_\pi} \left(\frac{Y_t}{Y} \right)^{\kappa_Y} \right)^{1-\rho_R} \exp(\varepsilon_{R,t})$
Lagged Shadow Rate (Demand Shocks)	$R_t^* = (R_{t-1}^*)^{\rho_R} \left(R \left(\frac{\pi_t}{\pi} \right)^{\kappa_\pi} \left(\frac{Y_t}{Y} \right)^{\kappa_Y} \right)^{1-\rho_R} \exp(\varepsilon_{R,t}),$ $\sigma_A = \sigma_{SFA} = \sigma_{Y^*} = \sigma_{A_L} = \sigma_{u_\ell} = \sigma_{u_K} = \sigma_{A_P} = \sigma_{A_T} = 0$
Lagged Actual Rate (Demand Shocks)	$R_t^* = R_{t-1}^{\rho_R} \left(R \left(\frac{\pi_t}{\pi} \right)^{\kappa_\pi} \left(\frac{Y_t}{Y} \right)^{\kappa_Y} \right)^{1-\rho_R} \exp(\varepsilon_{R,t}),$ $\sigma_A = \sigma_{SFA} = \sigma_{Y^*} = \sigma_{A_L} = \sigma_{u_\ell} = \sigma_{u_K} = \sigma_{A_P} = \sigma_{A_T} = 0$
<i>Share of Ricardian Households</i>	
99% Ricardian Households	$\mu = 0.99$
50% Ricardian Households	$\mu = 0.5$
<i>Risk Premium Shock Persistence</i>	
No Persistence in Risk Premium Shock	$\rho_{AB} = 0$
<i>Economic Openness</i>	
Closed Economy	$\nu_G = \nu_{G_I} = 0, \nu_C = \nu_I = 0.0001$
Closed Economy, No Foreign Shocks	$\nu_G = \nu_{G_I} = 0, \nu_C = \nu_I = 0.0001,$ $\sigma_{Y^*} = \sigma_{\pi^*} = \sigma_{R^*} = \sigma_{A_S} = \sigma_{A_T} = 0$

Table 5 – Counterfactual Simulations: GDP and Inflation Changes in Moments Relative to Baseline (%)

Counterfactual Model Assumptions	GDP		Inflation	
	Std	Mean	Std	Mean
<i>Automatic Stabilisers</i>				
No Automatic Stabilisers	11.06	0.10	0.04	–0.03
<i>Monetary Policy Response</i>				
Weaker Monetary Pol. Response to Inflation	–23.19	–0.77	2.42	–0.29
Weaker Monetary Pol. Response to Output Gap	17.02	–0.02	–0.25	0.37
<i>Endogenously Binding ELB</i>				
Lagged Shadow Rate	–1.53	–0.46	0.02	0.20
Lagged Actual Rate	–2.78	–1.15	0.14	0.16
Lagged Shadow Rate (Demand Shocks)	0.70	–0.04	0.01	0.02
Lagged Actual Rate (Demand Shocks)	12.63	–0.15	0.51	0.03
<i>Share of Ricardian Households</i>				
99% Ricardian Households	–2.42	0.00	–0.03	–0.01
50% Ricardian Households	3.10	0.00	0.03	0.01
<i>Risk Premium Shock Persistence</i>				
No Persistence in Risk Premium Shock	–8.42	0.09	–0.02	0.05
<i>Economic Openness</i>				
Closed Economy	–5.75	–0.72	0.32	0.54
Closed Economy, No Foreign Shocks	10.80	–0.24	0.95	0.13

Where the relative standard deviation of GDP is calculated as $\left(\frac{\text{std}(Y_t^{CF})}{\text{std}(Y_t^{BL})} - 1\right) \times 100$ and the relative standard deviation of inflation is calculated as $(\text{std}(\pi_t^{CF}) - \text{std}(\pi_t^{BL})) \times 100$, CF is the counterfactual and BL is the baseline. The relative mean of GDP is calculated as $\left(\frac{\bar{Y}^{CF}}{\bar{Y}^{BL}} - 1\right) \times 100$ and the relative standard deviation of inflation is calculated as $(\bar{\pi}^{CF} - \bar{\pi}^{BL}) \times 100$, where the bars indicate sample means.

The Monte Carlo filtering exercise indicates that reduced automatic stabilisers are more likely to result in higher government consumption multipliers. To understand the implications on macroeconomic stability, I simulate an extreme case of an economy without automatic stabilisers. This is achieved by setting the output elasticities in the fiscal rules to zero: $\psi_G, \psi_{G_I}, \psi_{Z_N}, \psi_{Z_S}, \psi_K, \psi_\ell = 0$.³⁹ Compared to the baseline simulation, GDP is 11% more volatile without automatic stabilisers. According to the model, reducing automatic stabilisers to enhance government consumption multipliers would increase the volatility of GDP, running counter to the goals of stabilisation policy. The effects on the means of both GDP and inflation, and the standard deviation of inflation are much smaller.

To demonstrate the impact of weakening the monetary policy response to inflation on the properties of GDP and inflation, I simulate the model with $\kappa_\pi = 1.0001$, so that monetary policy only just satisfies the Taylor principle. This leads to GDP that is 23% less volatile than the baseline, but it also results in substantially more inflation volatility with the standard deviation of inflation 2.4 percentage points higher than the baseline. It also leads to GDP

³⁹ Strictly speaking, automatic stabilisers will still be operating in the model when the parameters that govern the sensitivity to the business cycle are set to zero. This is because stable/acyclical government spending provides stabilisation to the economy and even with the output elasticity on tax rates set to zero, tax revenues will still exhibit some procyclicality.

that is on average 0.77% lower than the baseline.⁴⁰ Reducing the monetary response to inflation to boost government consumption multipliers leads to more volatile inflation and a lower average level of GDP, according to the counterfactual model simulations.

A weaker monetary policy response to the output gap is associated with larger government consumption multipliers. I set $\kappa_Y = 0$ and simulate the model to investigate the effects of a reduction in the monetary policy response to the output gap on GDP and inflation. I find output is 17% more volatile than the baseline in this case. The effects on the mean of GDP are small, while inflation is 0.25 percentage points less volatile but 0.37 percentage points higher on average. Reducing or eliminating the monetary policy response to the output gap in order to enhance government consumption multipliers leads to more volatile GDP, according to the simulation results.

Government consumption multipliers are larger when interest rates are at the lower bound. Government consumption multipliers calculated at the lower bound when the shadow rate is a function of the lagged actual interest rate are larger than when the shadow rate is a function of the lagged shadow interest rate. Simulating the model with a lower bound constraint results in GDP that is 1.5% and 2.8% less volatile than the baseline case where the lower bound does not bind, depending on the shadow rate assumption used. A reduction in the volatility of GDP when the lower bound constraint is occasionally binding would suggest that the impact of supply shocks is dominating the effect of demand shocks. In general the effects of demand shocks are amplified at the lower bound, while the effects of supply shocks are reduced. This is because positive demand shocks generate more inflation at the lower bound, reducing the real interest rate, providing additional stimulus which further increases demand. Positive supply shocks at the lower bound are disinflationary or even deflationary, contributing to higher real interest rates which are contractionary, offsetting some of the effects of the shock. If enough simulation periods are constrained by the lower bound and supply shocks are on average more important than demand shocks, the dampening effect of the lower bound on supply shocks results in lower GDP volatility.

To investigate the stabilisation properties of the economy when subject to an occasionally binding lower bound constraint and faced with only demand shocks, I re-run the simulations, including the baseline, with only demand shocks.⁴¹ In this case I find the simulation with the shadow rate that is a function of the lagged shadow rate has GDP that 0.7% more volatile than the baseline, with a negligible increase in inflation volatility. However, when the simulation is re-run with the shadow rate as a function of the lagged actual interest rate, GDP is 13% more volatile than the baseline and inflation is 0.5% more volatile. While this specification results in larger government consumption multipliers, it also has worse demand stabilisation properties due to its lack of history dependence when compared with the alternative shadow rate specification, and the baseline simulation where the lower bound was not imposed. A similar point was made in Section 5 where the fall in both output and inflation was larger for the specification of the shadow rate that was a function of the lagged actual interest rate. Christiano et al. (2011) make the observation that recessions with a higher output cost at the lower bound are related to higher government spending multipliers. My results suggest that demand driven recessions are larger when the shadow rate is a function of the lagged actual interest rate.

Government consumption multipliers are more likely to be large when the share of Ricardian households is small. I run counterfactual simulations with the share of Ricardian

⁴⁰ Because the model is non-linear and I use a non-linear solution and simulation methodology, Jensen's inequality means the simulations will not necessarily be centered on their steady states.

⁴¹ Demand shocks are determined by looking at the model's IRFs. Shocks that result in a positive co-movement of inflation and GDP on impact are deemed demand shocks.

households set at 99% and 50% and compare the results against the baseline calibration where 70% of households are Ricardian. When the share of Ricardian households is increased to 99%, the volatility of GDP drops by 2.4%. When the share of Ricardian households is reduced to 50%, the volatility of GDP increases by 3.1%. Ricardian households are better able to self-insure against shocks, while rule of thumb households, unable to save, own assets or borrow, are more vulnerable to economic shocks. A larger share of rule of thumb households amplifies the effects of government consumption shocks, but also amplifies the effects of other shocks in the model. In a world with fewer Ricardian households, government consumption multipliers are likely to be larger, but this comes at the expense of increased GDP volatility.

When government consumption multipliers are calculated at the endogenously binding lower bound, their size increases (decreases) as the risk premium shock becomes more (less) persistent. The risk premium shock is particularly significant because it is the shock that is used to produce the recession scenarios that make the lower bound constraint bind. A more (less) persistent risk premium shock process implies a larger (smaller) and more prolonged (shorter) recession and more (less) time spent at the effective lower bound. To test the impact of changes in the persistence of the risk premium shock on GDP and inflation, I *reduce* the persistence of the risk premium shock process from the posterior mode of 0.78 to 0 in the counterfactual simulation. Reducing the persistence of the risk premium shock lowers the volatility of GDP by 8% relative to the baseline. A more persistent risk premium shock process, which is more likely to lead to larger government consumption multipliers at the lower bound due to its effects on the depth and persistence of the recession, and the duration of the lower bound binding, is also consistent with a more volatile economy in general.

A smaller share of imports in government consumption is associated with higher government consumption multipliers, according to the Monte Carlo filtering exercise. I run two simulations to investigate the impact of the degree of openness on the volatility and levels of GDP and inflation. In the first simulation, I set the foreign bias parameters so that $\nu_C = \nu_I = 0.0001$ and $\nu_G = \nu_{G_I} = 0$ and simulate the model. I then repeat the first simulation, switching off the foreign shocks, the export shock, the imported tradeables cost push shock, and exchange rate shock. I label this simulation “No Foreign Shocks”. I also re-run the baseline simulation with the same shocks switched off for comparison. This is key, because trade and a flexible exchange rate also enhance the stabilising properties of the economy for domestic shocks and due to the addition of the foreign shocks, the open economy model will be subject to more sources of variation than the closed economy model. When comparing the first set of simulations with the baseline results that includes foreign shocks, GDP is nearly 6% less volatile in the closed economy. Comparing the second set of simulations with the updated baseline simulation that does not include foreign shocks, GDP is nearly 11% more volatile. This illustrates that while the closed economy is less volatile, this is due to the presence of foreign shocks in the baseline simulation. Once the foreign shocks are controlled for, the open economy with its flexible exchange rate, and a degree of risk sharing, is less volatile than the closed economy. While government consumption multipliers may be larger in a closed economy, GDP may be more volatile in the absence of a flexible exchange rate and other risk sharing channels.

These simulation exercises highlight the potential tension and trade-off between strengthening an economy’s stabilisation properties and strengthening the impact of discretionary government fiscal policy. Many features that amplify the impact of government consumption shocks, also amplify the effects of other shocks in the model, especially the other demand shocks. This is particularly true when thinking about the role the lower bound on interest rates and the shadow rate play in amplifying government consumption shocks along with

other demand shocks in the model. In forward looking models, history dependence is a property of optimal policy and optimal simple rules due to its macroeconomic stabilisation properties. History dependence means future monetary policy should respond to current shocks. Smoothing in interest rate rules embodies history dependence, so that current monetary policy responds to past shocks. Interest rate smoothing also has a greater effect on long-term interest rates. Small persistent changes in short-term interest rates have a larger impact on long-term interest rates when communicated to the public and long-term interest rates are a key driver of both consumption and investment in standard DSGE models (see Woodford 2003, for example). History dependent monetary policy at the lower bound (when the shadow interest rate is a function of the lagged shadow rate) reduces volatility at the lower bound and reduces the size of fiscal multipliers. When the shadow rate is a function of the lagged actual interest rate government consumption multipliers are larger (see Hills & Nakata 2018, for examples in a small New Keynesian DSGE model). This highlights a tension between amplifying fiscal multipliers at the expense of good stabilisation policy. Many properties of policy and the economy that increase government consumption multipliers, especially at the lower bound, are likely to worsen the stabilisation properties of the economy.

This trade-off may be reflected in the way some governments think about the relationship between automatic stabilisers and discretionary fiscal policy. Some studies have suggested that automatic stabilisers and discretionary fiscal policy are treated as substitutes by policymakers. Using cross country data and measures of the strength of both discretionary fiscal policy and automatic stabilisers, Fatás (2019) shows there is a small negative correlation between the use of discretionary fiscal policy and automatic stabilisers. For example countries like the US and Japan that have particularly weak automatic stabilisers have been shown to make more use of discretionary fiscal policy. The apparent substitutability of these policies by policymakers may also reflect the fact that the impact and effectiveness of discretionary fiscal policy is reduced in economies that have good stabilisation properties including stronger automatic stabilisers.

9. Conclusion

I calculate government consumption multipliers for New Zealand in this paper using an estimated small open economy monetary-fiscal DSGE model under a number of different monetary policy settings. In particular, I investigate government consumption multipliers in normal times, at the endogenously binding lower bound under two different shadow interest rate assumptions, and given an interest rate pegged for 4 quarters, and also 8 quarters. I also use prior predictive analysis to investigate the range of government consumption multipliers implied by both the model and prior specifications for the same monetary policy assumptions, and I use Monte Carlo filtering to determine which features of the model are more likely to contribute to larger government consumption multipliers.

Using counterfactual stochastic simulations, I show how some of the features of the model economy that contribute to larger government consumption are also simultaneously associated with greater macroeconomic instability. On the methodological side, I show how parameter uncertainty can be incorporated into the calculation of fiscal multipliers at the endogenously binding lower bound by normalising the interest rate paths using conditional forecasting techniques with the extended path algorithm.

I find government consumption multipliers in New Zealand are positive but less than 1 in normal times. At the lower bound, government consumption consumption multipliers are larger than in normal times, but still lower than 1. When the interest rate is pegged for at least 2 years, government consumption multipliers can be larger than 1. Prior

predictive analysis shows that the model is consistent with a range of fiscal multipliers, but estimation typically narrows and reduces the multipliers implied by the priors. Monte Carlo filtering highlights a number of parameters that are important for determining the size of government consumption multipliers. In particular, New Zealand's status as a small open economy with moderate automatic stabilisers is likely to reduce the impact of discretionary fiscal policy. I show that many of the factors that contribute to larger government consumption multipliers also contribute to more volatility in the economy, leading to a potential trade off between strengthening discretionary fiscal policy at the expense of macroeconomic stabilisation. This may explain, at least in part, why there is some evidence that discretionary fiscal policy and automatic stabilisers are treated as substitutes over a cross section of countries.

The prior predictive analysis and Monte Carlo filtering tools used to investigate government consumption multipliers in this paper can also be used to investigate other fiscal multipliers. The model I use has separate treatments for government investment, transfer payments, capital and labour income taxes and consumption tax, and can produce multipliers for each of these fiscal instruments. I leave the application of these tools to other fiscal instruments for future work. The forward guidance puzzle has been highlighted as a potential issue with DSGE models when considering monetary policy stimulus provided by the lower bound (see Del Negro et al. 2023). I do not investigate whether the model used in this paper is subject to the forward guidance puzzle and what implications this may have for fiscal multipliers calculated at the lower bound. Kolasa et al. (2022) provide an empirically testable behavioural modification for small open economy DSGE models that reduces the effects of the forward guidance puzzle. This approach could be applied to the model used in this paper to deal with the forward guidance puzzle if this is an issue. I leave the investigation of the forward guidance puzzle and potential modifications of the model for future work.

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A. Data

I estimate the model using 19 quarterly time series variables that span the 1994Q1 to 2019Q4 period. The variables, descriptions and data descriptions are listed in Table 6. The transfers and tax revenue data are all nominal and highly seasonal, so I divide them by the CPI and seasonally adjust them using the x13 filter. Net core Crown debt is annual, so I interpolate it to make it quarterly. I assume that the foreign economy is 80% US and 20% Australia. The foreign output variable, inflation and the interest rate are all constructed using these weights. I use the TWI exchange rate which has a 0.92 correlation with an 80 20 USD/NZD AUD/NZD weighted exchange rate. All variables are Hodrick Prescott filtered to produce gaps except for domestic inflation, wage inflation, foreign inflation and the foreign interest rate. I use a smoothing parameter of 100,000 in the Hodrick Prescott filter. Quarterly domestic inflation, wage inflation and foreign inflation are demeaned. The foreign interest rate is linearly detrended. I transform the domestic and foreign interest rates into quarterly series by dividing by 4 and this is what I match with the model's measurement equations.

Table 6 – Model Data

Variable	Description	Data Description	Treasury/Stats NZ data identifiers
\hat{Y}_t	Output gap	Gross Domestic Product - expenditure measure	NGDP_ZQ/SNEQ.SG02RSC00B15
\hat{R}_t	Nominal interest rate gap	New Zealand: Bank Bill Yields: 90-Days (Percent)	R90D11AMQ
$\hat{\pi}_t$	Inflation gap	Consumers Price Index: All groups	PCPIQ/CPIQ.SE9A
$\hat{\pi}_{W,t}$	Wage inflation gap	Average hourly earnings; Ordinary time; By sector: Private Sector	LQHOPRZQ
\hat{Y}_t	Unemployment gap	Unemployed; Total both sexes; New Zealand: Unemployment Rate	LHURZQ/HLFQ.S1F3S
\hat{I}_t	Investment gap	Gross Fixed Capital Formation - Total Market and Non-Market - Private	NIP_ZQ/SNEQ.SG02RSC01P51T1
\hat{C}_t	Consumption gap	Final Consumption Expenditure - Private Non Profit Organisations and Households Combined	NCP_ZQ/SNEQ.SG02RSC30P30G
\hat{M}_t^*	Export gap	Exports of Goods and Services	NZ_ZQ/SNEQ.SG06RSC00P60
\hat{G}_t	Government consumption gap	Final Consumption Expenditure - General Government	NCG_ZQ/SNEQ.SG02RSC30P30C
$\hat{G}_{I,t}$	Government investment gap	Gross Fixed Capital Formation - Total Market and Non-Market - General Government	NIG_ZQ/SNEQ.SG02RSC01P51T5
\hat{Z}_t	Transfers gap	Treasury calculations, Consumers Price Index: All groups	PCPIQ/CPIQ.SE9A
$\hat{T}_{C,t}$	Consumption tax revenue gap	GST revenue, Consumers Price Index: All groups	FTGSTM, PCPIQ/CPIQ.SE9A
$\hat{T}_{\ell,t}$	Labour tax revenue gap	Individual tax revenue, Consumers Price Index: All groups	FTINDVLM, PCPIQ/CPIQ.SE9A
$\hat{T}_{K,t}$	Capital tax revenue gap	Corporates, Residents interest, Residents dividends, Consumers Price Index: All groups	FTCPM, FTRWTM, FTTDWTM, PCPIQ/CPIQ.SE9A
$\frac{\hat{B}_t}{\hat{Y}_t}$	Government debt to GDP gap	Core Crown net debt, Gross Domestic Product - expenditure measure	FANDIFRSA, NGDP_ZQ/SNEQ.SG02RSC00B15
$\frac{\hat{S}_t}{\hat{S}_{t-1}}$	Exchange rate growth rate gap	New Zealand: Trade-Weighted Exchange Rate Index	RTWI11AMQ
\hat{Y}_t^*	Foreign GDP gap	Real Gross Domestic Product	IUSGDP_ZQ, IAUGDP_ZQ
$\hat{\pi}_t^*$	Foreign inflation gap	CPI-U: All Items, Consumer Price Index	IUSCPIQ, IAUCPIQ
\hat{R}_t^*	Foreign interest rate gap	Federal Funds Effective Rate, Percent, Quarterly, Not Seasonally Adjusted, 3-Month or 90-day Rates and Yields: Bank Bills for Australia, Percent, Quarterly, Not Seasonally Adjusted	FEDFUNDS, IR3TBB01AUM156N

B. Parameterisation

In this section I discuss the model's calibration and estimation results.

B.1 Calibration

I start by describing the calibration of key model parameters. These are mainly parameters that affect the steady state or are difficult to estimate.

I start by setting capital's share of income, α , to 0.3. Jacob & Munro (2016) use the same value in a DSGE model calibrated to match New Zealand data. This is in the neighbourhood of Smith & Thoenissen (2019) who estimate capital's share of income to be 0.33 for New Zealand.

The elasticity of output with respect to public capital, α_G , is chosen to be 0.07. Plausible values of this parameter typically range between 0 and 0.12 in the literature. In an estimation exercise, Traum & Yang (2015) evaluate the marginal data density under 3 different calibrations of this parameter (0, 0.05 and 0.10). They find only small differences between the respective marginal data densities. Likewise, Watson & Tervala (2022) find a posterior mean estimate of 0.084 for Australia for this parameter, centered on a prior with mean 0.083.⁴² These studies suggest this parameter is difficult to estimate. Leeper et al. (2010b) calibrate this parameter, setting it at a value that ensures the marginal product of public capital is slightly lower than private capital. I follow the same approach when calibrating the parameter in this study.

The discount factor, β , is set to 0.9975 consistent with a steady state real interest rate of 1%. This is lower than the average real interest rate over the 1994Q1 to 2019Q4 period the model is estimated on. The lower calibrated value is more consistent with recent history. The real interest rate averaged about 1% over the 2010Q1 to 2019Q4 period. A lower real interest rate also means that a less dramatic and more plausible recession is needed when calculating fiscal multipliers at the endogenously binding lower bound.

The quarterly depreciation rates of private and public capital, δ and δ_G respectively, are both set to 0.025, consistent with an annual depreciation rate of 10%. This is a commonly used figure in models without trend growth and it is reasonably consistent with the long run average investment GDP ratio (see Table 9). This is the same value used by Jacob & Munro (2016) for the depreciation of private capital in a model calibrated to match New Zealand data. Smith & Thoenissen (2019) estimate this parameter finding a posterior mode of 0.027, which is in the vicinity of the value used here.

I set the elasticity of substitution between differentiated intermediate goods, ε , to 6, implying a steady state mark-up of 20%. Jacob & Munro (2016) use 10, implying a markup of 10%, while Funke et al. (2018) also use 6 as the elasticity of substitution between differentiated intermediate goods in a model estimated and calibrated to match New Zealand data. The elasticity of substitution between differentiated labour varieties, η , is set to 6.0113 which is consistent with a steady state unemployment rate of 5%.

I set the inverse of the intertemporal elasticity of substitution, γ , to 1, consistent with log utility. This helps ensure the initial response of consumption to a total factor productivity shock is positive. Larger values for γ result in a smaller initial response from the Ricardian

⁴² Watson & Tervala (2022) find the data is informative for estimating most parameters except for the elasticity of output with respect to public capital and the depreciation rate of public capital.

household, which is more likely to lead to an undesirable fall in aggregate consumption following a total factor productivity shock.

I assume that only labour taxes respond to deviations of net debt from target to simplify the model's fiscal responses. This means setting $\gamma_G = \gamma_{G_I} = \gamma_K = \gamma_{Z_N} = \gamma_{Z_S} = 0$. Allowing the other fiscal instruments to respond to debt results in more complicated dynamics.

The share of Ricardian households, μ , is set to 0.7, so that 30% of households are rule of thumb. Typically the parameter μ is set between 0.6 and 0.75, with smaller values usually implying larger consumption responses to fiscal policy, due to the rule of thumb household's inability to self insure and the further weakening of Ricardian equivalence.⁴³

I use the Statistics New Zealand National Accounts input-output tables to set the bias parameters in the production of final private consumption, final government consumption, final private investment and final government investment. The import input coefficient weights for 2007, 2013 and 2020 are reported in Table 7. The weights for the private and government consumption are relatively stable over the 3 different snapshots. The share of imports in gross fixed capital formation has fallen from 0.38 in 2007 to 0.32 in 2020. I set the import bias in consumption, ν_C , to 0.25, the import bias in government consumption, ν_G , to 0.12 and the import bias parameters for both government investment, ν_{G_I} , and private investment, ν_I , to 0.4. These values are slightly higher than the numbers listed in the the input-output tables because imports are also an input to exports, which is not captured in the model. Slightly higher values are also required to match the steady state ratio of imports to GDP with the long run average in the data as shown in Table 9. The input-output tables do not make the distinction between private and public gross fixed capital formation, so I use the same value for the import bias parameter for both aggregation functions.

Table 7 – Input Coefficient Weights: Imports

Year	Final Consumption Expenditure - Households	Final Consumption Expenditure - Central Government	Final Consumption Expenditure - Local Government	Gross Fixed Capital Formation
2007	0.225	0.115	0.120	0.381
2013	0.225	0.104	0.120	0.344
2020	0.226	0.102	0.105	0.324

Source: Statistics New Zealand National Accounts Input-Output Tables 2020, 2013 & 2007.

I set the import bias parameter in the foreign country, ν^* , to 0.3 so that it is reasonably symmetric with the home country.⁴⁴

The weight on the capacity utilisation adjustment cost, ψ_1 , is chosen to match the steady state level of the rental rate on capital, as per equation (311) in the online appendix. The net foreign debt elasticity in the risk premium, ϕ_S , is set equal to 0.01. This parameter tends

⁴³ Distortionary taxation, as used in this model, breaks Ricardian equivalence. Introducing a rule of thumb household also breaks Ricardian equivalence.

⁴⁴ Due to the small open economy assumption and the use of autoregressive processes to model the foreign economy, it is the product of the import bias parameter and foreign GDP that determines steady state demand for exports. As equation (352) in the online appendix makes clear, changes in the import bias parameter will only have implications for the steady state level of foreign GDP required to solve the steady state model.

to be set at a relatively small number so as to limit its effects on the model's dynamics.

I set the consumption tax rate, τ_C to 0.15, which is the current rate of goods and services tax (GST) in New Zealand.⁴⁵ The average tax rate on labour income, τ_ℓ , is set to 0.18, close to the average tax rate on labour income over the 1994Q1 - 2019Q4 period. Based on OECD calculations, the average tax rate on labour income over the 2000 - 2021 period is 18.7%, with a peak tax rate of 21.1% and a bottom rate of 15.9% (see OECD 2022). Coleman (2019) reports an average labour income tax rate of 18.1% for New Zealand. I set the average tax rate on capital income, τ_K , to 0.28. This tax rate is more difficult to pin down due to the way capital income is taxed in New Zealand. In particular New Zealand taxes dividend income in the hands of the holder at their marginal tax rate. A tax rate of 28% is consistent with the corporate income tax rate in New Zealand and would be consistent with equities being held by taxpayers with higher incomes. It also produces a steady state investment to GDP ratio that is reasonably close to the average in the data as illustrated in Table 9.⁴⁶

The steady state gross quarterly inflation rate, π , is set at 1.005, consistent with an annual inflation target of 2%.

I switch off persistence in the shock to the government's budget constraint by setting $\rho_{SFA} = 0$. I switch off the labour preference shock by setting $\rho_\kappa = \sigma_\kappa = 0$. This is because this shock can cause unemployment to go below zero in numerical simulation exercises. I assume that most transfer payments in New Zealand are going to agents with a higher marginal propensity to consume. Consistent with this assumption I set transfers to the Ricardian household equal to zero so that all transfers are paid to the rule of thumb household and I set $Z_S = \rho_{Z_S} = \sigma_{Z_S} = 0$ to ensure that the transfers spending rule for the Ricardian household is not active either.

The full list of calibrated parameters can be found in Table 8.

⁴⁵ The GST rate was increased from 12.5% to 15% on 1 October 2010. I keep the rate constant over the estimation period for simplicity. Allowing for a time varying steady state GST rate over history would have implications for the model's steady state, complicating the estimation of the model.

⁴⁶ Unlike labour and consumption tax rates, the capital income tax rate affects the steady state calculation of the great ratios. The investment to GDP ratio is a decreasing function of the capital income tax rate.

Table 8 – Calibrated Parameters

Parameter	Description	Value
<i>Intermediate Production</i>		
α	Capital's share of income	0.3
α_G	The elasticity of output with respect to public capital	0.07
<i>Capital Accumulation</i>		
δ	The depreciation rate for private capital	0.025
δ_G	The depreciation rate for public capital	0.025
<i>Household</i>		
β	The discount factor	0.9975
γ	The inverse of the intertemporal elasticity of substitution	1
μ	Share of Ricardian households	0.7
<i>Elasticities</i>		
ε	The elasticity of substitution between intermediate goods	6
η	The elasticity of substitution between labour varieties	6.0113
ϕ_S	Net foreign debt elasticity in risk premium	0.01
ψ_1	Weight on capacity utilisation adjustment cost	0.0275
<i>Fiscal Rule*</i>		
γ_G	Government consumption's response to debt	0
γ_{G_I}	Government investment's response to debt	0
γ_K	Capital tax's response to debt	0
γ_{Z_N}	Rule of thumb transfers response to debt	0
γ_{Z_S}	Ricardian transfers response to debt	0
<i>Import Bias</i>		
ν^*	Domestic bias in foreign production	0.3
ν_C	Import bias in consumption	0.25
ν_G	Import bias in government consumption	0.12
ν_{G_I}	Import bias in government investment	0.4
ν_I	Import bias in investment	0.4
<i>Tax Rates</i>		
τ_C	Average tax rate on consumption expenditure	0.15
τ_K	Average tax rate on capital income	0.28
τ_ℓ	Average tax rate on labour income	0.18
<i>Shock Persistence</i>		
ρ_{SFA}	Persistence of public debt shock process	0
ρ_κ	Persistence of labour preferences shock process	0
ρ_{Z_S}	Persistence of transfers to Ricardian households	0
<i>Shock Standard Deviations</i>		
σ_κ	Shock standard deviation labour preferences	0
σ_{Z_S}	Shock standard deviation for transfers to Ricardian households	0

* : The labour tax response to government debt is estimated.

Table 9 – Great Ratios

Ratio	Description	Calibrated Value	Data
$\frac{C}{Y}$	Consumption to GDP	0.60	0.58
$\frac{I}{Y}$	Investment to GDP	0.20	0.17
$\frac{G}{Y}$	Government consumption to GDP	0.15	0.18
$\frac{G_I}{Y}$	Government investment to GDP	0.05	0.05
$\frac{M}{Y}$	Imports to GDP	0.27	0.28
$\frac{X}{Y}$	Exports to GDP	0.27	0.29
$\frac{Z}{Y}$	Transfers to GDP	0.10	0.10
$\frac{B}{4 \times Y}$	Government debt to GDP	0.3	
$\frac{F}{4 \times Y}$	Net foreign debt to GDP	-0.7	-0.67
\mathfrak{R}	Quarterly gross real interest rate	1.0025	
π	Quarterly gross CPI inflation rate	1.005	
Υ	Unemployment rate	0.05	
$\frac{T_K}{Y}$	Capital income tax revenue to GDP	0.08	0.06
$\frac{T_L}{Y}$	Labour income tax revenue to GDP	0.13	0.13
$\frac{T_C}{Y}$	Consumption tax revenue to GDP	0.09	0.09

B.2 Estimation Results

The estimated parameters, along with their prior distributions are reported in Tables 10, 11 and 12.

As pointed out by Canova et al. (2019), in large models with many shocks, it is unlikely that all shocks will represent important independent structural disturbances driving the economy. Following Ferroni et al. (2019) I use priors for the estimated shock standard deviations with a mode of 0 so as not to overstate the role of less important shocks.

The estimated parameters fall within plausible ranges. I note that the mean of the inverse of the Frisch elasticity of labour supply, 3.52, is quite a bit higher than the prior mean of 2. Galí et al. (2012) estimate an inverse Frisch elasticity of labour supply of 3.99 for the US in a model with the same specification of unemployment.

The weight on habit formation is 0.10. This is likely to be lower than the prior mean due to the penalty on parameterisations of the model that generate a negative consumption response to positive technology shocks. Rule of thumb consumption also adds to the persistence of consumption reducing the need for habit formation.

Table 10 – Estimated Parameters

Parameter	Description	Prior*	Prior Mean	Prior Std	Post Mean	Post Std
<i>Household Preferences</i>						
θ	Weight on habit formation	β	0.50	0.10	0.10	0.03
ξ	Inverse of the Frisch labour supply elasticity	\mathcal{N}	2.00	0.25	3.52	0.18
<i>Real Rigidities</i>						
χ	Elasticity of capacity utilisation costs	\mathcal{N}	2.00	0.50	2.15	0.45
ϕ_I	Weight on investment adjustment costs	Γ	6.00	1.00	6.81	0.89
ϕ_X	Weight on export adjustment costs	\mathcal{N}	2.00	0.25	1.99	0.27
<i>Nominal Rigidities</i>						
ϕ_W	Weight on wage adjustment costs	Γ	200.00	20.00	178.95	17.66
ϕ_P	Weight on domestic price adjustment costs	Γ	200.00	20.00	189.43	19.23
ϕ_F	Weight on imported price adjustment costs	Γ	200.00	20.00	195.33	18.76
ι_W	Weight on wage indexation	β	0.50	0.10	0.25	0.07
ι_P	Weight on domestic price indexation	β	0.50	0.10	0.24	0.06
ι_F	Weight on imported price indexation	β	0.50	0.10	0.19	0.05
<i>Aggregation Function Elasticities</i>						
μ_C	EoS between domestic and imported goods in consumption	β	1.50	0.25	2.46	0.20
μ_I	EoS between domestic and imported goods in investment	β	1.50	0.25	1.90	0.24
μ_G	EoS between domestic and imported goods in government consumption	β	1.50	0.25	1.63	0.25
μ^*	EoS between foreign and exported goods in foreign final goods	β	1.50	0.25	1.27	0.28
μ_{G_I}	EoS between domestic and imported goods in government investment	β	1.50	0.25	1.59	0.25
<i>Monetary Policy</i>						
κ_π	Weight on inflation in the Taylor-type rule	\mathcal{N}	1.50	0.50	2.21	0.22
κ_y	Weight on the output gap in the Taylor-type rule	\mathcal{N}	0.12	0.01	0.12	0.01
ρ_R	Weight on interest rate smoothing in the Taylor-type rule	β	0.50	0.10	0.87	0.02
<i>Fiscal Policy</i>						
ψ_ℓ	Labour tax response to the output gap	Γ	1.00	0.50	1.94	0.45
ψ_K	Capital tax response to the output gap	Γ	1.00	0.50	0.89	0.44
ψ_G	Government consumption response to the output gap	Γ	1.00	0.50	0.23	0.11
ψ_{G_I}	Government investment response to the output gap	Γ	1.00	0.50	0.61	0.33
ψ_{Z_N}	Rule of thumb transfers response to the output gap	Γ	1.00	0.50	0.89	0.26
γ_ℓ	Labour tax response to public debt	Γ	0.40	0.20	0.12	0.05

* Key: \mathcal{N} = normal distribution, Γ = gamma distribution, β = beta distribution. EoS = Elasticity of substitution.

Table 11 – Estimated Parameters: Shock Persistences

Parameter	Description	Prior	Prior Mean	Prior Std	Post Mean	Post Std
ρ_A	Technology shock	β	0.50	0.10	0.91	0.02
ρ_{A_I}	Investment efficiency shock	β	0.50	0.10	0.28	0.07
ρ_{A_P}	Stochastic subsidy in domestic production	β	0.50	0.10	0.25	0.06
ρ_{A_T}	Stochastic subsidy in imported goods	β	0.50	0.10	0.21	0.05
ρ_{A_S}	External risk premium shock	β	0.50	0.10	0.86	0.03
ρ_{M^*}	Export demand shock	β	0.50	0.10	0.69	0.06
ρ_{A_B}	Risk premium shock	β	0.50	0.10	0.81	0.03
ρ_{A_L}	Labour demand shock	β	0.50	0.10	0.70	0.05
ρ_η	Elasticity of differentiated labour shock	β	0.50	0.10	0.25	0.07
ρ_{u_C}	Consumption tax shock	β	0.50	0.10	0.52	0.07
ρ_{u_ℓ}	Labour tax shock	β	0.50	0.10	0.68	0.07
ρ_{u_K}	Capital tax shock	β	0.50	0.10	0.41	0.10
ρ_{u_G}	Government consumption	β	0.50	0.10	0.82	0.04
$\rho_{u_{Z_N}}$	Rule of thumb transfers shock	β	0.50	0.10	0.46	0.08
$\rho_{u_{G_I}}$	Government investment shock	β	0.50	0.10	0.53	0.07
ρ_{Y^*}	Foreign GDP shock	β	0.50	0.10	0.89	0.02
ρ_{π^*}	Foreign inflation shock	β	0.50	0.10	0.34	0.07
ρ_{R^*}	Foreign interest rate shock	β	0.50	0.10	0.88	0.02

Table 12 – Estimated Parameters: Shock Standard Deviations

Parameter	Description	Prior	Prior Mean	Prior Std	Post Mean	Post Std
σ_A	Technology shock	\mathcal{N}	0.00	0.40	0.0136	0.0015
σ_{A_I}	Investment efficiency shock	\mathcal{N}	0.00	0.40	0.2357	0.0357
σ_{u_C}	Consumption tax shock	\mathcal{N}	0.00	0.40	0.0299	0.0021
σ_{u_ℓ}	Labour tax shock	\mathcal{N}	0.00	0.40	0.0366	0.0026
σ_{u_K}	Capital tax shock	\mathcal{N}	0.00	0.40	0.0660	0.0069
σ_{u_G}	Government consumption shock	\mathcal{N}	0.00	0.40	0.0131	0.0010
$\sigma_{u_{G_I}}$	Government investment shock	\mathcal{N}	0.00	0.40	0.0917	0.0069
$\sigma_{u_{Z_N}}$	Rule of thumb transfers shock	\mathcal{N}	0.00	0.40	0.0375	0.0027
σ_R	Monetary policy shock	\mathcal{N}	0.00	0.40	0.0016	0.0001
σ_{A_P}	Stochastic subsidy in domestic production	\mathcal{N}	0.00	0.40	0.2311	0.0337
σ_{A_S}	External risk premium shock	\mathcal{N}	0.00	0.40	0.0061	0.0011
σ_{A_T}	Stochastic subsidy in imported goods	\mathcal{N}	0.00	0.40	0.5708	0.0722
σ_{A_B}	Risk premium shock	\mathcal{N}	0.00	0.40	0.0068	0.0010
σ_{A_L}	Labour demand shock	\mathcal{N}	0.00	0.40	0.0554	0.0076
σ_η	Elasticity of differentiated labour shock	\mathcal{N}	0.00	0.40	1.0655	0.1252
σ_{SFA}	Public debt shock	\mathcal{N}	0.00	0.40	0.0121	0.0009
σ_{M^*}	Export shock	\mathcal{N}	0.00	0.40	0.0812	0.0098
σ_{Y^*}	Foreign GDP shock	\mathcal{N}	0.00	0.40	0.0071	0.0005
σ_{π^*}	Foreign inflation shock	\mathcal{N}	0.00	0.40	0.0054	0.0004
σ_{R^*}	Foreign interest rate shock	\mathcal{N}	0.00	0.40	0.0010	0.0001

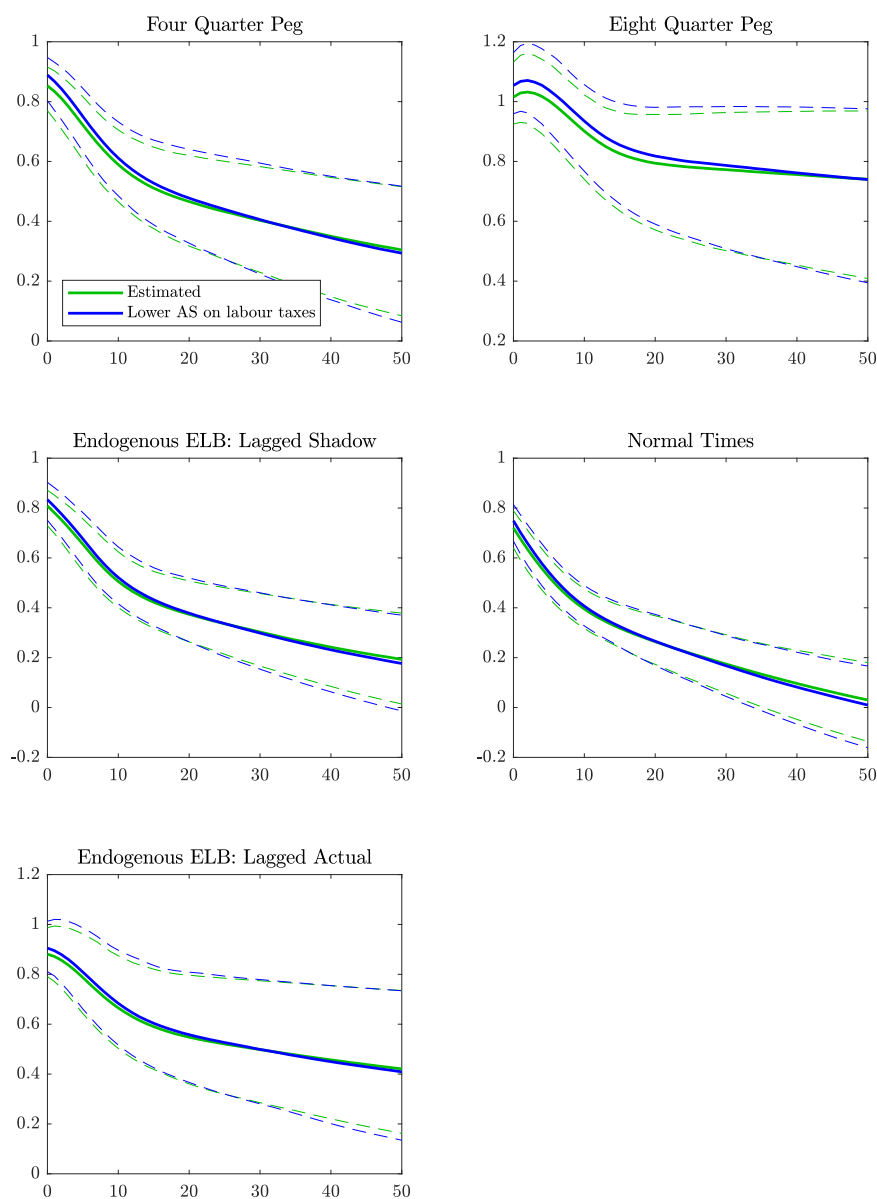
C. Monte Carlo Filtering

Table 13 – Monte Carlo Filtering: Parameters and their Uniform Support

Parameter	Parameter Range	Parameter	Parameter Range
μ	0.5 – 0.99	μ_G	0.5 – 3
χ	0.01 – 100	μ^*	0.5 – 3
ξ	0.33 – 8	μ_{G_I}	0.5 – 3
Υ	0.03 – 0.06	κ_π	1 – 5
α_G	0 – 0.12	κ_Y	0 – 1
ν_C	0.01 – 0.4	ρ_R	0 – 1
ν_I	0.01 – 0.4	ψ_C	0 – 3
ν_G	0.01 – 0.4	ψ_ℓ	0 – 3
ν_{G_I}	0.01 – 0.4	ψ_K	0 – 3
ϕ_I	0 – 10	ψ_G	0 – 3
θ	0 – 1	ψ_{G_I}	0 – 3
γ	1 – 5	ψ_{Z_N}	0 – 3
ϕ_W	50 – 400	γ_ℓ	0.05 – 1
ϕ_P	50 – 400	ι_P	0 – 1
ϕ_F	50 – 400	ι_W	0 – 1
ι_F	0 – 1	ρ_{AB}	0 – 1
μ_C	0.5 – 3	ρ_{u_G}	0 – 1
μ_I	0.5 – 3	ϕ_X	0 – 4

D. Lower Automatic Stabilisers on Labour Taxes

Figure 15 – Lower Automatic Stabilisers on Labour Taxes



The green lines represent results from the model using the estimated response of labour tax rates to the output gap. The blue lines represent an alternative parameterisation where the labour tax rate's response to the output gap, ψ_ℓ is set to 0.25 which is more consistent with the OECD's estimates of labour tax revenue's response to the output gap. The dashed lines represent 99% bands capturing estimated parameter uncertainty. Solid lines represent the median of the simulations.