Essays on fiscal policy in South Africa

by

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Declaration

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This dissertation includes one original paper published in a peer-reviewed journal and two unpublished publications/chapters. The development and writing of the papers (published and unpublished) were the principal responsibility of myself and, for each of the cases where this is not the case, a declaration is included in the dissertation indicating the nature and extent of the contributions of co-authors.

Date: . . . .

Abstract

This study is primarily motivated by the renewed interest in the effects of fiscal policy on general macroeconomic outcomes and macroeconomic stability since the 2008/09 Global Financial Crisis. In the wake of the crisis, it became apparent that both the standard and unconventional monetary policy toolkits were insufficient to stimulate global demand to the degree required. As such, there was renewed debate on the role of discretionary fiscal policy in stabilising the global economy.

In light of the resurgence in interest on the effects of fiscal policy on broader macroeconomic outcomes, as well as the relative dearth of research on the topic in South Africa, this study investigates several aspects of the economy-wide transmission of fiscal policy decisions within the South African context.

Chapter 2 provides microeconomic evidence of the behavioural responses of individual taxpayers to changing tax rates. The magnitude of this behavioural response is central to the formulation of tax and transfer policies. Using a new dataset comprising confidential tax return data, the elasticity of taxable income (ETI) is estimated. The estimate lies close to the mid-point of estimates found in the literature. Furthermore, it is shown that behavioural responses to changing tax rates are concentrated in higher-income groups. Finally, through embedding the ETI estimate in an optimal tax framework it is shown that there is little scope for raising marginal rates.

Chapter 3 broadens the scope and investigates the transmission of unanticipated fiscal policy innovations to broader macroeconomic aggregates, including GDP and private consumption. A key aim of the chapter is to estimate fiscal multipliers. Using a variety of identification approaches and model specifications, it is found that, while the size of budgetary multipliers is sensitive to the identification strategy and modelling approach used, government spending multipliers are positive and smaller than one. Tax multipliers are found to be large and distortionary.

Chapter 3 estimates fiscal multipliers based on empirical reduced-form models. A different approach to the identification of fiscal shocks and their transmission to macroeconomic outcomes is through estimated dynamic stochastic general equilibrium (DSGE) models. To that end, Chapter 4 specifies and estimates an open-economy fiscal DSGE model for the South African economy. While fiscal multipliers are generally in line with estimates from Chapter 3, the size of budgetary multipliers depends crucially on the specific policy rule that is used to stabilise debt, i.e. the functional form of the fiscal rules. The specific features embedded in the model, including the specification of nominal rigidities and consumer behaviour, also play a vital role in determining the size of the fiscal multipliers.

Opsomming

Na afloop van die 2008/09 Internasionale Finansiële Krisis was daar hernude belangstelling in die impak van fiskale beleid op makro-ekonomiese uitkomste, asook die impak van hierdie beleidsbesluite op makro-ekonomiese stabiliteit. In die afloop van die krisis het dit vinnig duidelik geraak dat beide tradisionele én buitengewone monetêre beleidsmaatreëls nie voldoende was om globale groei genoegsaam aan te wakker nie. Dus het die aandag verskuif na fiskale beleid en het daar hewige debat onstaan oor die vermoeë, al dan nie, van diskresionêre fiskale beleid om die wêreldekonomie te stabiliseer en globale groei 'n hupstoot te gee.

Aan die hand van die hernude belangstelling in fiskale beleid na afloop van die krisis, en die algemene gebrek aan navorsing in hierdie veld in Suid-Afrika, bekyk hierdie studie verskeie aspekte van die transmissie van fiskale beleid na makro-ekonomiese uitkomste binne die Suid-Afrikaanse konteks.

Hoostuk 2 verskaf mikro-ekonomiese insigte oor veranderinge in individuele gedragspatrone na 'n aanpassing in die marginale belastingkoers. Kennis van hierdie veranderende gedragspatrone speel 'n belangrike rol in die formulering van beleid rondom belasting en maatskaplike (of ander) toelae. Een maatstaf wat hierdie gedragsverandering kwantifiseer is die sogenaamde elastisiteit van belasbare inkomste (EBI). Die EBI vir Suid-Afrika word beraam met behulp van 'n nuwe datastel bestaande uit individuele belastingopgawes. In die algemeen, wys die resultate dat die waarde van die EBI vir Suid-Afrika naby aan die middelpunt van die beramings in die breër literatuur lê. 'n Verdere toepassing van die EBI is in die berekening van sogenaamde optimale belastingkoerse. Die beraamde waarde van die EBI vir Suid Afrika dui dat daar min ruimte vir addisionele verhogings in marginale koerse is, veral onder hoë inkomste groepe.

In Hoofstuk 3 verskuif die fokus na die makro-ekonomiese impak van fiskale beleidbesluite. Die hoofdoel van die hoofstuk is om sogenaamde fiskale vermenigvuldigers (*"fiscal multipliers"*) te beraam. Hierdie vermenigvuldigers gee die verandering in spesifieke makro-ekonomiese veranderlikes, insluitend BBP, na afloop van 'n eksogene verandering in fiskale beleid. Die resultate wys dat die grootte van hierdie vermenigvuldigers afhang van beide die tegniek wat gebruik word om fiskale skokke te identifiseer, sowel as die spesifieke modelspesifikasie. Desnieteenstaande dui die beramings daarop dat bestedingsvermenigvuldigers positief maar kleiner as een is, terwyl belastingvermenigvuldigers relatief groot is.

In Hoofstuk 4 word 'n strukturele model van die Suid-Afrikaanse ekomomie gebou in 'n poging om die impak van fiskale beleid te kwantifiseer. In die hoofstuk word 'n sogenaamde dinamiese stochastiese algemene ekwilibrium (*"Dynamic Stochastic General Equilibrium"*) model beraam. Die model bevat a gedetailleerde fiskale blok met volledig gespesifiseerde fiskale gedragsreëls. Die model word gebruik om die impak van fiskale beleidsbesluite onder verskillende omstandighede te meet, met spesifieke verwysing na die impak van die tipe fiskale instrument wat gebruik word om die skuldlas te stabiliseer na afloop van 'n fiskale skok. Die bevindinge beaam die resultate van Hoofstuk 3 - bestedingsvermenigvuldigers is positief maar kleiner as een, terwyl belastingvermenigvuldigers negatief is. Die grootte van die vermenigvuldigers hang egter af van die funksionele vorm van die fiskale gedragsreël en die spesifieke eienskappe van die model.

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Publications

A version of Chapter 2 has appeared in the *Economic Research of South Africa* working paper series as 'The Elasticity of Taxable Income: The case of South Africa'.

A version of the same chapter is forthcoming as 'The Elasticity of Taxable Income: The Case of South Africa' in the *South African Journal of Economics*.

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Chapter 1

Introduction

This research study is primarily motivated by the renewed interest in the effects of fiscal policy since the 2008/09 Global Financial Crisis (henceforth GFC), i.e. government's spending and tax policy, on general macroeconomic outcomes and macroeconomic stability, as well as the interaction between monetary and fiscal policy in a world where the lines between the two sets of policy instruments have become blurred.

Given the unprecedented size and scope of the GFC, it came as no surprise that the policy response was unusually aggressive, particularly in the developed world. As a first response to the sharp drop in activity during and immediately after the GFC, monetary authorities the world over slashed policy rates in an attempt to stimulate demand. Interest rates in the developed world dropped to close to the zero lower bound and has remained there ever since, while rates in the developing world also fell sharply. The response in South Africa was not nearly of the same magnitude as that of the developed world, but the policy rate did fall from 12% in late 2008 to 7% by the end of 2009 before dropping even further as it became evident that the economy remained weak.

However, it soon became apparent that the standard monetary policy toolkit was insufficient to offset the fall in economic activity. Against this backdrop, authorities the world over turned to unconventional monetary policy and discretionary fiscal policy in an attempt to arrest the decline in output. Unconventional operations altered central banks' balance sheets in both size and substance, and the magnitude of these operations was significant. These quasi-fiscal policies were employed in conjunction with traditional monetary and fiscal policy measures in an attempt to stimulate demand. Few economic observers expect this mix of macroeconomic policies to persist indefinitely. In fact, while so-called Quantitative Easing (QE) continues in Europe and Japan, it has run its course in the US. Importantly, the unwinding of the stimulus measures could have unforeseen consequences in a world where the lines between monetary and fiscal policy have become somewhat blurred. Some have worried that quasi-fiscal policies may undermine central banks' independence and ability to stabilise inflation (Sims, 2001; Goodfriend, 2011), while others have noted that the efficacy of said policy measures depends critically on expectations regarding future monetary-fiscal policy regimes (Davig and Leeper, 2011).

The main objective of these stimulus measures was to spur economic activity by increasing aggregate demand and, in so doing, support job creation. However, as the world continues to suffer the consequences of the biggest financial meltdown since the Great Depression, ten years after the fact the efficacy of the numerous policy measures implemented in the wake of the GFC remains open for debate.

Both standard and unconventional monetary policy appeared insufficient to stimulate global demand. This reignited the debate on the role of discretionary fiscal policy in stabilising the global economy. Across the globe, fiscal policy was employed in concert with the fall in interest rates and the expansion of central bank balance sheets in an attempt to bolster economic growth. In the US, Congress passed the $787 billion American Recovery and Investment Act in early 2009, in addition to the $125 billion provided by the Economic Stimulus Act of 2008. Across the Atlantic, various stimulus measures were also implemented in Europe. While the policy response in South Africa was not nearly of the same magnitude as that of the developed world, the government employed active fiscal policy (mainly in the form of increased public consumption expenditure) in an attempt to stimulate economic activity.

The typical argument in favour of fiscal activism is that stimulus raises consumption demand and, consequently, the demand for labour, thereby creating employment and stimulating economic activity. However, it is somewhat ironic that the consumption response is the key element of the transmission mechanism as the empirical evidence does not universally support the idea that increased government spending raises private consumption. The size of fiscal multipliers, which measures the output response to changes in fiscal variables, is the source of much contention at both the theoretical and empirical level. In fact, there is no theoretical consensus on the size or sign of fiscal multipliers (see, for example, Ramey, 2011a), while no consensus has yet been reached on the empirical methodology to be used in estimating said multipliers (see, for example, Engemann et al., 2008; Ramey, 2011b).[1]

Apart from the debate surrounding the impact of fiscal policy on macroeconomic activity, the large-scale fiscal stimulus programmes implemented in the wake of the GFC has also ignited renewed interest in the possible long-term impact of persistent government budget deficits and the associated increase in public debt ratios, particularly in an environment of weak economic growth. In the US, the budget deficit increased from 2.1% of GDP in 2007 to 12.1% in 2009 and has since only slowly contracted to measure 3.8% in 2018. Over the same period, the US government debt-to-GDP increased from 64.8% to over 100%. Domestically, rising deficits in the wake of the crisis has also resulted in a sharp increase in the government debt burden - the government budget balance moved from a surplus of 1% of GDP in 2007 to a deficit of 6.3% in 2010 and has since averaged around 4.5% of GDP, with the gross debt-to-GDP ratio climbing from 23% to 51% between 2007 and 2018.

Recent decades have produced ample evidence of the harmful effects of large and unsustainable fiscal deficits (and increases debt burdens) on macroeconomic performance (Calitz et al., 2013). It should be noted that not all of the deterioration in government finances since the GFC was the result of discretionary fiscal policy. Automatic stabilisers, including the deterioration in tax bases on the back of falling economic activity and widespread job losses, likely contributed the larger share of the deterioration in public finances. Be that as it may, fiscal activism did return to favour in the wake of the GFC and likely contributed to the deterioration of the fiscal position of governments the world over. In fact, given the extent of the policy intervention, a new focus on the interaction between short-term stimulus and the long-term sustainability of fiscal positions is required. Importantly, as suggested in Calitz et al. (2013), the discretionary fiscal decisions undertaken by the South African government between 2007 and 2010 might pose a serious threat to fiscal sustainability unless the authorities respond by reining in large and unsustainable budget deficits and the accompanying increase in government debt.

Conversely, any fiscal consolidation plans need to be viewed through the lens of the possible impact they may have on economic activity in the short run. The eruption of the European debt crisis in 2011 resulted in widespread fiscal austerity programmes in a bid to get government finances under control. As a result, a new branch of the fiscal policy literature developed with the aim of estimating the effects of these consolidation plans on economic activity (Pereira and Wemans, 2013). Critics of the austerity programmes blame the initiative for the continued

[1] Also see seminal contributions by Ramey and Shapiro (1998), Blanchard and Perotti (1999), Perotti (2004), Galí et al. (2007), Hall (2009), Mountford and Uhlig (2009), and Barro and Redlick (2011), among others.

under-performance of European economies. Closer to home, the South African government has committed to fiscal prudence by reining in spending and raising taxes, despite persistent pressure on the fiscus in the from new spending programmes and financial support for struggling State Owned Enterprises (SOE). This again emphasises the need to better understand the transmission of fiscal policy shocks to broader macroeconomic outcomes. Whether fiscal consolidation should proceed by cutting expenditure or raising taxes, or indeed if it should proceed at all, crucially depends on the differential impact of these policy tools on macroeconomic aggregates.

Finally, while there is a considerable international literature investigating the effects of fiscal policy on macroeconomic outcomes, very little work has been done in the South African context. Notable exceptions include Du Plessis et al. (2007), du Plessis and Boshoff (2007), Jooste et al. (2013), Calitz et al. (2013), and Jooste and Naraidoo (2017), among a few others. Such research is of particular importance in an environment where calls for expansionary fiscal (and monetary) policy have become all the more frequent and vociferous against the background of anaemic economic growth outcomes.

In light of the resurgence in interest on the effects of fiscal policy on broader macroeconomic outcomes, as well as the relative dearth of research on the topic in South Africa, this research study investigates several aspects of the economy-wide transmission of fiscal policy decisions within the South African context.

Brief summary

Chapter 2: The Elasticity of Taxable Income

Chapter 2 provides microeconomic evidence of the behavioural responses of individual taxpayers to changing tax rates. The magnitude of this behavioural response is central to the formulation of tax and transfer policies, as well as the study of the welfare implications of tax decisions. In this regard, the elasticity of taxable income, or ETI, is a key concept. The ETI aims to capture all possible behavioural responses to changes in income taxation, including tax evasion and/or avoidance, in a single measure, without the need to specify the nature of the adjustment processes involved.

Using a new dataset comprising confidential tax return data made available for research purposes by the South African Revenue Service (SARS) and the National Treasury, Chapter 2 estimates the ETI for South Africa using the 'bracket creep' phenomenon to identify the parameters of interest. The ETI is estimated at around 0.3 and lies close to the mid-point of estimates found in the literature. Behavioural responses are concentrated in higher-income groups as suggested by the higher elasticity estimate (0.37 for taxable income) for the top 10% of income earners.

The elasticity estimates are used as inputs in an optimal taxation framework, which shows that the optimal tax rate for the top 10% of income earners is in line with a legislated marginal personal income tax rate of around 40%. Important from a policy perspective is the conclusion that significant increases in the legislated marginal tax rate could trigger behavioural responses that could nullify any potential revenue gain.

Chapter 3: Empirical estimates of fiscal multipliers for South Africa

Chapter 3 shifts the focus to the impact of fiscal policy decisions on macroeconomic aggregates, including GDP, private consumption, and private investment. A key aim of the chapter is to estimate budgetary multipliers, i.e. the output response following an *exogenous* shock of intervention to fiscal policy variables, be it a shock to government spending or taxes. The size of these fiscal multipliers has been a source of contention in the international literature at both the theoretical and empirical level. In fact, in the empirical literature, which is largely based on structural vector autoregressions (SVARs), there is little agreement on the size, and even the sign, of fiscal multipliers. Caldara and Kamps (2008), Chahrour et al. (2012), Ramey (2016), and Caldara and Kamps (2017), among others, show that the wide range of fiscal multiplier estimates found in the literature is mainly due to differences in the approach used to identify the underlying (structural) fiscal shocks.

Chapter 3 contributes to the literature by estimating fiscal multipliers for South Africa using a variety of identification approaches and model specifications. The main findings show that the size of budgetary multipliers is indeed sensitive to identification strategy and modelling approach. Despite this caveat, in general the estimation results show that government spending multipliers are positive, albeit generally smaller than one. In contrast, tax multipliers are found to be large and distortionary.

Chapter 4: A medium-sized, open-economy, fiscal DSGE model of South Africa

Chapter 3 estimates fiscal multipliers based on reduced-from, empirical models, with at most an *ad hoc* structural interpretation. A different identification approach is through estimated dynamic stochastic general equilibrium (DSGE) models, introduced by Smets and Wouters (2003, 2007). DSGE models identify fiscal shocks, and their transmission to macroeconomic outcomes, by imposing structure based on economic theory and estimates fiscal multipliers through impulse response analysis. The DSGE framework allows for the specification of detailed fiscal blocks, with several fiscal instruments, and facilitates the estimation of the economic consequences of shocks to these instruments.

To that end, Chapter 4 specifies and estimates an open-economy fiscal DSGE model for the South African economy, where the fiscal block includes three government spending and three tax instruments. The estimated model fits the data reasonably well and is used to simulate the effect of innovations to the different fiscal instruments on macroeconomic aggregates, including GDP, private consumption and private investment.

The results highlight the fact that the fiscal policy process is highly complex and that the impact of fiscal policy decisions on broader macroeconomic outcomes depends crucially on assumptions about which fiscal policy variables adjust to stabilise debt. That being said, policy simulations indicate that government spending and investment multipliers are generally positive, albeit smaller than one. Multipliers are also generally smaller than the estimates presented in Chapter 3, consistent with the idea that spending multipliers are smaller in open-economy settings. Secondly, the estimates indicate that taxes are highly distortionary, with large negative multipliers for private consumption and investment. In contrast, the impact of tax shocks on output is highly ambiguous, with assumptions regarding which instruments adjust to debt and the size of automatic stabilisers playing an important role. Finally, a look at debt dynamics indicate that government consumption spending and, to a slightly lesser extent, labour and consumption taxes are the most effective instruments for stabilising debt after a fiscal shock.

Chapter 4 contributes to the growing international, and burgeoning South African, literature on fiscal multiplier estimates and counter-factual policy simulations using a DSGE approach. The model includes a detailed fiscal block, small open-economy features, and household heterogeneity in order to better capture the effects of fiscal policy in the South African context. As such, the chapter not only contributes to the scant literature on South Africa, but it also adds to the international discourse on optimal fiscal policy design.

The research study investigates several aspects relating to the effect of fiscal policy decisions on economic outcomes, including the impact on individual behaviour and broader macroeconomic aggregates, within the South African context. The broad conclusion is that fiscal policy decisions can have large and distortionary effects on the broader economy. The study provides valuable insight into the functioning of the South African economy and the research contributes meaningfully to the burgeoning fiscal policy literature in South Africa. It also develops a new tool for fiscal policy analysis in the form of an estimated open-economy DSGE model with a detailed fiscal block.

Chapter 2

The Elasticity of Taxable Income

in South Africa over the sample period

2.1 Introduction

The behavioural response of taxpayers to changing marginal tax rates has long been a topic of interest to economists. The size of this parameter is central to the formulation of tax and transfer policies, as well as the study of the welfare implications of tax decisions. Public finance practitioners are often asked to predict responses to alternative policy changes and to provide empirical estimates of the effects to decision-makers (Thoresen and Vattø, 2013). To this end, it is important to quantify the size of the behavioural responses of individuals to changing policy parameters.

In this regard, the elasticity of taxable income, or ETI, is a key concept. The ETI aims to capture all possible behavioural responses to changes in income taxation, including tax evasion and/or avoidance, in a single measure, without the need to specify the nature of the adjustment processes involved (Creedy, 2009; Thoresen and Vattø, 2013).[2] This allows policy-makers to evaluate the likely impact of policy proposals on both taxpayer behaviour and policy outcomes (such as the impact on tax revenue due to a change in marginal tax rates).

Modelling the response to tax rates in this reduced form way, as opposed to formulating a structural model of the behaviour involved, has proven to be very attractive. As mentioned in Saez et al. (2012), a large body of literature has developed that seeks to estimate the ETI, as well as elasticities for other related income measures. Most of this literature has focused on individual taxable income in the United States, Canada, and Western Europe, while a limited number of studies have focused on countries outside these regions.

Very little work has been done in the South African context. Given the lack of access to micro-level panel data on personal income taxes (PIT), studies that have attempted to estimate the ETI for South Africa focused primarily on publicly available aggregated tax data. Using a new dataset comprising confidential tax return data made available for research purposes by the South African Revenue Service (SARS) and the National Treasury, this chapter estimates the ETI for South Africa. Given the importance of PIT in overall tax collection in South Africa (PIT is the single largest contributor to tax revenue, accounting for 35% of total gross tax collected

[2] These adjustments could include labour supply changes (at both the extensive and/or intensive margins), income shifting between sources which are taxed at different rates, and tax evasion through non-declaration of income.

between 2000 and 2018), the study is restricted to estimating the ETI as it applies to personal income taxes and individual marginal tax rates.[3]

Due to the lack of large legislated tax reforms in South Africa over the sample period, which are often used to identify the ETI, this chapter follows Saez (2003) in employing the 'bracket creep' approach to identify the elasticity. Using the 'bracket creep' approach, the elasticity for taxable income is estimated at around 0.3, while that for broad income is estimated at closer to 0.2. Additionally, it is found that behavioural response to changing tax rates, as captured by the ETI, are concentrated in higher-income groups as suggested by the higher elasticity estimate (0.37 for taxable income) for the top 10% of income earners.

An important application of ETI estimates is in determining optimal marginal tax rates. Most studies on optimal taxation focus on the top 1% of the income distribution. However, since there is no exogenous variation in tax rates for the top 1% of the distribution in the current sample, this chapter focuses on the top 10% of income earners. Embedding the elasticity estimate of 0.37 for the top 10% of income earners in an optimal tax framework, it is determined that the optimal marginal tax rate for this group is around 48% (consistent with a legislated marginal PIT rate of around 40%).

The rest of the chapter proceeds as follows: Section 2.2 discusses the basic conceptual framework and unpacks the various identification issues that arise when attempting to estimate the ETI in practice. Section 2.2 provides a brief review of the international empirical literature. Section 2.3 estimates the ETI for South Africa using micro-level tax return data and Section 2.4 discusses optimal taxation results. Section 2.5 presents some caveats and concluding comments.

2.2 Theoretical Framework and Literature Review

2.2.1 Basic Model[4]

In the standard labour supply model, individuals maximise a general utility function $u(c, l)$, where c is consumption and l is labour supply. Total labour income is given by $w \cdot l$, where w is the exogenous wage rate. The (linearised) budget constraint is given by $c = w \cdot l \cdot (1 - \tau) + R$, where τ is the marginal tax rate and R is virtual income (that is, non-wage income equal to the intercept of the linear section of the budget constraint extended to the c axis, where $l = 0$).

The ETI literature generalises this model by noting that hours worked (or labour supply) is just one of the possible behavioural responses to income taxation. Other responses include intensity of work effort, career choice, the form and/or timing of remuneration, and the avoidance or evasion of income tax. As a result, an individual's wage rate w might depend on both effort as well as the individual's response to changing tax rates. Reported taxable income could, therefore, differ from total earnings ($w \cdot l$) as individuals could split their total gross income between taxable (cash) remuneration and other forms of non-taxable compensation, such as fringe benefits, or they might even fail to report their full taxable income through different avoidance and/or evasion strategies (Saez et al., 2012).

As shown in Feldstein (1999), a simple way to jointly model all these responses is to assume that individual utility depends positively on disposable income c (which in this simple model is equal to consumption) and negatively on taxable income z (since activities that generate income

[3]While the larger share of the international literature has also focused on personal income taxes (PIT) and the response of individuals to changes in marginal tax rates, most of the conceptual and empirical issues discussed remain relevant for other tax bases, such as corporate income taxes (CIT).

[4]Following Saez (2001), Gruber and Saez (2002), and Saez et al. (2012)

might be costly if, for example, it requires foregoing leisure).[5] As such, individuals maximise utility $u(c, z)$ subject to the linearised budget constraint $c = z \cdot (1 - \tau) + R$, where z is before tax (taxable) income and R is virtual income. The maximisation of the utility function leads to a 'reported income' supply function which is a function of the slope of the budget line and virtual income: $z = z(1 - \tau, R)$. Changes in τ and R affect reported income as follows:

$$dz = -\frac{\partial z}{\partial(1-\tau)}d\tau + \frac{\partial z}{\partial R}dR \tag{2.2.1}$$

Following Gruber and Saez (2002) and introducing the uncompensated elasticity of taxable income with respect to the net-of-tax rate $e^u = \frac{(1-\tau)}{z}\frac{\partial z}{\partial(1-\tau)}$ and the income effect parameter $\eta = \frac{(1-\tau)\partial z}{\partial R}$, one has:

$$dz = -e^u z \frac{\partial \tau}{1-\tau} + \eta \frac{dR}{1-\tau} \tag{2.2.2}$$

Introducing the compensated ETI, e^c, and using the Slutsky equation $e^c = e^u - \eta$, it can be shown that:

$$\frac{dz}{z} = -e^c \frac{d\tau}{1-\tau} + \eta \frac{dR - zd\tau}{z(1-\tau)} \tag{2.2.3}$$

where $dR - zd\tau$ is the change in after-tax income due to the tax change for a given before-tax income z, or the change in tax liability for taxpayers with income z. Equation (2.2.3), therefore, decomposes the change in reported income in response to a change in the marginal tax rate into a substitution effect (or the behavioural response of the taxpayer) and an income effect.

In much of the ETI literature, income effects are assumed away so that the income supply function $z(\cdot)$ only depends on the net-of-tax rate, $1 - \tau$. This equates to setting $\eta = 0$ in (2.2.3). As mentioned in Saez et al. (2012), there is no consensus in the labour supply literature on the size of income effects, with several studies finding small and insignificant effects. There are, however, some important studies that find large income effects, suggesting that the effect cannot be wholly ignored.[6] In the ETI literature, there is much less empirical evidence on the size of income effects.[7]

If one assumes away income effects (i.e. $e^c = e^u = e$), the goal of the ETI literature amounts to estimating the elasticity of taxable (or reported) income with respect to the net-of-tax rate, defined as

$$e = \frac{(1-\tau)}{z}\frac{\partial z}{\partial(1-\tau)} \tag{2.2.4}$$

or the percent change in reported income when the net-of-tax rate increases by 1 percent. As shown in Feldstein (1999), this quantity captures not just the labour supply response, but also all other responses to changes in marginal tax rates.

The estimation of this elasticity has taken on two distinct forms. The first is based on the standard labour supply model and attempts to model behavioural responses in a structural way.[8]

[5] A logarithmic functional form was used for utility, where utility is increasing in income and decreasing in reported income.

[6] See Blundell and Macurdy (1999) for a survey of the relevant literature.

[7] Gruber and Saez (2002) estimated both income and substitution effects for the US and find small and insignificant income effects.

[8] See Saez (2001), Gruber and Saez (2002), and Saez et al. (2012)

Using cross-sectional observations on households' and individuals' consumption and connections to the labour market (typically through a measure of hours worked), it is possible to directly apply a labour supply function or estimate a utility function.[9] These parameter estimates can, in turn, be used to simulate the effects on hours worked and/or income of hypothetical changes to the tax system (Thoresen and Vattø, 2013). This approach forms the basis for much of the literature on microsimulation tax models.

While such discrete-choice labour supply models remain key instruments in predicting the effects of policy changes, concerns have been raised about their ability to generate robust predictions (see LaLonde, 1986; Angrist and Pischke, 2010; Imbens, 2010, among others).

This brings us to the second broad approach to modelling the behavioural response to changing taxation, as pioneered by Lindsey (1987) and Feldstein (1995). It is mainly based on the analysis of observations before and after a realised policy reform. In this tradition, policy reforms are seen as quasi-experiments. The approach has been extended to incorporate identification strategies not necessarily focused on specific tax reforms; these include using the phenomenon of 'bracket creep' to obtain elasticity estimates (Saez, 2003) and using of bunching analysis to estimate income responses around kink points in the tax schedule, as developed by Saez (2010) and extended by Chetty et al. (2011), among others.

While the reduced form approach has gained in popularity, it has limited value in a prediction context because the estimation relies on a particular reform for identification, making it less useful when assessing new policy changes.[10] Despite this apparent shortcoming, the relative simplicity of the approach has proven to be attractive. It uses information about incomes, which is normally more easily accessible than data on hours worked, and exploits standard econometric techniques.

Importantly, the ETI is not a structural parameter that depends solely on individual preferences. It depends crucially on the features of the tax system, such as exemptions, opportunities for deductions, and the availability of other avoidance mechanisms. Therefore, the ETI may not be constant over time and depends crucially on the structure and nature of the tax system.

Finally, Saez et al. (2012) show that, under certain circumstances, the compensated elasticity, e^c, is a sufficient statistic for welfare and optimal tax analysis. However, the presence of income shifting (both over time and between tax bases), anticipation effects, and large-scale tax evasion could bias welfare and optimal tax analysis. However, these effects are not as prominent in the current set-up since the reform used for identification (i.e. 'bracket creep') is not legislated and/or announced well in advance (the approach is discussed in detail below). As such, there is little scope for income shifting and/or evasion in anticipation of the change to marginal rates.

Several issues arise when attempting to estimate the ETI in practice. The next section will discuss some of the identification issues that arise in the empirical literature.

2.2.2 The Main Identification Problem

A simple model of income reporting behaviour can serve to illustrate some of the identification issues in the estimation of the ETI. Following Saez et al. (2012), it is assumed that in year t, individual i reports income equal to z_{it} and faces a marginal tax rate $\tau_{it} = T'(z_{it})$. Reported (or taxable) income is assumed to respond to marginal tax rates with elasticity e so that $z_{it} = z_{it}^0 \cdot (1 - \tau_{it})^e$, where z_{it}^0 is income reported when the marginal tax rate is zero, i.e. potential income.

[9] See Blundell and Macurdy (1999) for a review of the literature.
[10] There are exceptions. See Carroll and Hrung (2005) and Thoresen et al. (2012), among others.

Using logs, one has that:

$$\log z_{it} = e \cdot \log(1 - \tau_{it}) + \log z_{it}^0 \tag{2.2.5}$$

Note that there are numerous assumptions built into this simple model. Firstly, the model abstracts from income effects on reported income. Second, the response of reported income to tax rates is immediate and permanent (i.e. the short-term and long-term elasticities are identical). Thirdly, the elasticity e is constant over time and uniform across the entire income distribution. Finally, individuals have perfect knowledge of the tax system and choose z_{it} after they know the exact realisation of z_{it}^0.[11]

Nevertheless, this simple framework serves to illustrate the main identification issue highlighted in the literature. Even under the simplifying assumptions embedded in the model, an OLS regression of $\log z_{it}$ on $\log(1 - \tau_{it})$ would produce biased estimates of the elasticity e since τ_{it} is positively correlated with $\log z_{it}^0$. This is because the marginal tax rate might increase with an increase in realised income in the presence of a graduated income tax schedule. Therefore, in order to identify the elasticity e, it is necessary to find instruments that are correlated with τ_{it}, but uncorrelated with $\log z_{it}^0$.

Much of the empirical literature has used reform-induced changes in the tax rate structure to obtain such instruments. By comparing the observed reported incomes after the change in tax structure to the incomes that would have been reported had the reform not taken place, the effects of the change in the net-of-tax rate can be isolated (Saez et al., 2012). Obviously, these counterfactual incomes are not observed and need to be estimated - an issue that has received much attention in the ETI literature.

A popular approach is to use reported incomes before a tax reform as a proxy for reported incomes after the reform. Essentially, this approach compares reported incomes before and after the reform and attributes the change in reported incomes to changes in tax structure. In many cases, however, a tax reform affects different subgroups of the population differently, and, in some cases, they leave tax rates essentially unchanged for most of the population. In this context, the group less affected by the reform can be used as a control group and can, therefore, be used to proxy the unobserved income changes for the affected group. This approach naturally leads to the consideration of difference-in-differences techniques.

Indeed, most of the recent literature on ETI has used micro-based difference-in-differences regressions in an attempt to overcome the main identification problem (Saez et al., 2012). Two widely used techniques are repeated cross-section analysis (see Saez et al., 2012) and panel analysis (see the seminal contribution by Feldstein, 1995).

Repeated Cross-Section Analysis

In this approach, changes in reported incomes for a treatment group, T, (i.e. a group affected by the tax change) are compared to changes for a control group, C, not affected by the tax change. t_0 and t_1 denote the pre- and post-reform years, respectively. Then, the following two-stage least squares regression can be estimated:

$$\log z_{it} = e \cdot \log(1 - \tau_{it}) + \alpha \cdot I(t = t_1) + \beta \cdot I(i \in T) + \varepsilon_{it} \tag{2.2.6}$$

where $I(\cdot)$ is the indicator function which takes the value of 1 if the condition in brackets is met. The regression in (2.2.6) is estimated on a repeated cross-section sample, which includes

[11] These assumptions can be relaxed in most cases, but it sometimes has important implications for identification.

both the treatment and control groups and both the year t_0 and year t_1 samples, using the post-reform and treatment group interaction $I(t = t_1) \cdot I(i \in T)$ as an instrument for $\log(1-\tau_{it})$ (Saez et al., 2012). The two-stage least squares estimate is a classical difference-in-differences estimator equal to:

$$e = \frac{([E(\log z_{it_1}|T) - E(\log z_{it_0}|T)] - [E(\log z_{it_1}|C) - E(\log z_{it_0}|C)])}{([E(\log(1-\tau_{it_1})|T) - E(\log(1-\tau_{it_0})|T)] - [E(\log(1-\tau_{it_1})|C) - E(\log(1-\tau_{it_0})|C)])} \tag{2.2.7}$$

Therefore, the elasticity estimate is defined as the ratio of the difference in the pre- and post-reform change in log incomes in the treatment group, minus the same difference for the control group, to a similar difference-in-differences measure defined in terms of the pre- and post-reform net-of-tax rates. As mentioned in Saez et al. (2012), the elasticity estimate will be unbiased only if the parallel trend assumption holds. That is the estimate will be unbiased if, absent the reform, the change in log-incomes would have been the same for both the control and treatment groups, i.e. the numerator would have been zero.

This brings us to a general concern in the ETI literature regarding the identification of elasticity estimates, namely the contamination of ETI estimates through changes in the (taxable) income distribution unrelated to changes in the tax structure. Reported incomes (for both treatment and control groups) can change over time for reasons unrelated to tax changes, which might lead to biased ETI estimates. One way to control for changes in the income distribution is to include separate time trends for the treatment and control groups in the regression framework.

Panel Analysis

Following the seminal contribution by Feldstein (1995), the majority of empirical studies that attempt to estimate the ETI have used panel data. With panel data, individual tax filers can be followed between pre- and post-reform years to identify income responses to changing tax rates.[12] Estimation of the ETI is carried out by running the two-stage-least-squares panel regression:

$$\log\left(\frac{z_{it_1}}{z_{it_0}}\right) = e \cdot \log\left(\frac{1-\tau_{it_1}}{1-\tau_{it_0}}\right) + \varepsilon_{it} \tag{2.2.8}$$

using the treatment indicator $I(i \in T)$ as an instrument.[13] This regression estimates a difference-in-differences parameter:

$$e = \frac{E(\log(\frac{z_{it_1}}{z_{it_0}})|T) - E(\log(\frac{z_{it_1}}{z_{it_0}})|C)}{E(\log(\frac{1-\tau_{it_1}}{1-\tau_{it_0}})|T) - E(\log(\frac{1-\tau_{it_1}}{1-\tau_{it_0}})|C)} \tag{2.2.9}$$

Again, the elasticity estimate is unbiased if the numerator is zero in the absence of a tax change. As stated above, this assumption might be violated if there are changes in the income distribution. However, another complication arises in the case of panel analysis. Even in the absence of a change in the income distribution, the identification assumption might be violated because of the presence of mean reversion in reported income. Mean reversion refers to the

[12] This is the strategy that will be followed in estimating the ETI for South Africa in Section 2.3

[13] Alternatively, as in Gruber and Saez (2002), one can use the predicted log change in the net-of-tax rate, $\log[(1-\tau_p)/(1-\tau_{t_0})]$, as an instrument, where τ_p is the predicted marginal tax rate that the individual would face if his real income did not change between pre- and post-reform years. More detail will follow when estimating the ETI for South Africa.

phenomenon that high incomes in year t_0 tend to be lower in the following years, especially if a large share of year t_0 income comprises positive transitory incomes. This produces a negative correlation between ε_{it} and z_{it_0} at the top of the income distribution. Similarly, mean reversion could produce a positive correlation at the bottom of the distribution.

To mitigate the mean reversion bias, as well as to control for potential changes in the income distribution, the recent literature has followed Auten and Carroll (1999) in introducing t_0 income controls in (2.2.8), either in a simple way by including $\log z_{it_0}$ or in a richer way by including polynomials or splines in base-year incomes. However, with a short time dimension (in this example only two years are used: pre- and post-reform), including income controls could destroy identification. This is because the inclusion of income controls absorbs much of the independent variation in tax rates, which are correlated with income.

To overcome this issue, following Gruber and Saez (2002), additional observations can be added to the regression by stacking differences across multiple years and adding year-specific dummy variables, as follows:

$$\log\left(\frac{z_{it+1}}{z_{it}}\right) = e \cdot \log\left(\frac{1-\tau_{it+1}}{1-\tau_{it}}\right) + f(z_{it}) + \alpha_t + \varepsilon_{it}, \qquad t = 0, 1, 2... \tag{2.2.10}$$

where $f(z_{it})$ denotes base-year income controls and α_t are year-specific dummies.

Panel analysis is particularly useful in cases where the aim is to analyse a tax change targeted at a specific sub-group of the population and there is a concern that the composition of this group might change over time. For example, suppose a tax change is targeted at the top end of the income distribution and that reported incomes of the top 1% change for reasons unrelated to the tax change (for example, new tax filers might enter the top of the distribution for reasons unrelated to the reform in question). In this scenario, the changing composition of the sub-group in question implies that repeated cross-section analysis will be biased. However, panel analysis will be unbiased (or at least less biased) since the same tax filers are followed over time. Additionally, panel data are required to study questions that are not directly related to the response of reported incomes to changing tax rates. For example, in order to study how tax policy might affect income mobility, panel data are clearly necessary.

One important shortcoming of panel analysis is that the identification restrictions lack transparency (Saez et al., 2012). The identification strategy discussed above mixes assumptions regarding mean reversion and assumptions relating to changes in the income distribution. It is often impossible to determine to what extent base-year income controls are controlling for mean reversion and to what extent they are controlling for a changing income distribution. Additionally, as mentioned above, these income controls absorb informative variation in tax rates which could hamper identification. To overcome this, Saez et al. (2012) suggest that it is important to include episodes of both increases and decreases in tax rates for the purpose of identification as mean reversion creates biases in opposite directions in the case of tax increases versus tax decreases.

Finally, it has been shown that panel regressions are relatively sensitive to the choice of instrument, suggesting that the standard methods do not adequately control for mean reversion and/or changes in the income distribution.

2.2.3 Other Identification Issues

Alternative Control Groups

The tax code itself might offer opportunities to identify alternative control groups that may be more comparable to the treatment group. For example, inflation or the loss of a personal exemption might push tax filers into higher tax brackets, and in some cases (particularly in the US) married and unmarried couples might experience different changes in tax schedules (Saez et al., 2012).[14]

The main advantage of this approach is the ability to compare individuals who are very similar in terms of income and initial marginal tax rates but face different prospects for changes in marginal rates.

The main disadvantage is that taxpayers are not always aware of the details of the tax code and the possible (localised) changes to their marginal tax rates that a reform might induce. As a result, the estimated elasticities might not be relevant for predicting behavioural responses in the case of well-publicised, broader tax changes.

This provides for the fundamental tension in tax response analysis: large reforms are likely to be noticed and acted upon by taxpayers, but often do not generate convincing control groups for identification purposes; on the other hand, small changes or reforms aimed at specific aspects of the tax code might generate better control groups, but are unlikely to produce generalisable elasticity estimates.

Tax Base Changes

The estimation of ETI focuses on the behavioural response of taxpayers to changes in marginal tax rates. However, the definition of the tax base that is subjected to the specific tax measure also changes periodically, often in conjunction with the change in the tax schedule. As mentioned in Gruber and Saez (2002) this raises several issues.

First, the estimated elasticity will be plausibly different in the post-reform era relative to the pre-reform era. For example, in the US, the Tax Reform Act of 1986 broadened the tax base by reducing deductions and the attractiveness of tax shelters. This resulted in a lower elasticity post-1986 than in the pre-reform era (as documented in Kopczuk, 2005). In cases such as this, even well-specified estimation strategies will yield an estimate of neither the pre- nor post-reform ETI, but rather a weighted average of the two (Saez et al., 2012).

Second, when the definition of the tax base changes, using the concurrent definition of taxable income as dependent variable in the regressions above runs the risk of confusing reform-induced changes in behaviour with purely definitional changes. The best course of action is to use a consistent definition of taxable income between the pre- and post-reform periods. However, as discussed in Saez et al. (2012), even if a consistent definition is used, the choice of which specific constant-law definition to use is not innocuous.

Capital Gains and Multiple Tax Rates

An additional complicating factor is the treatment of capital gains. Many studies of the ETI exclude capital gains from the definition of taxable income on the grounds that capital gains are often subject to a different marginal tax rate than normal income. Additionally, it has been found that capital gains' realisations are particularly sensitive to anticipated changes in the capital gains tax (see Burman et al., 1994). Some taxpayers have opportunities for converting wage and salary income into capital gains income and often do so when the tax advantages are sufficient. The tax advantage, in turn, depends crucially on the difference between the tax rates on ordinary income and capital gains income.

[14] See Saez (2003), Looney and Singhal (2006), Feldman and Katuščák (2009), and Singleton (2011), among others, for examples of the use of alternative control groups.

As such, the capital gains rate matters and should ideally be included in the analysis of the aggregate behavioural response to changes in the tax rate on ordinary income. However, given the difficulties in specifying a model of joint determination of capital gains and ordinary income, most studies exclude capital gains income from the measure of taxable (or more broadly defined) income.

2.2.4 Literature Review

Starting in the early 1990s, a large body of literature has developed with the aim of estimating the ETI and elasticities for related income measures. Most of this literature has focused on the United States, although some studies have estimated elasticities for Canada and Western Europe, while a limited number of studies have focused on countries outside these regions.

A selective review of the international literature on the estimation of the ETI will now follow.

ETI in the United States

Feenberg and Poterba (1993) used aggregate tax return data to investigate how the high-income share of taxable income in the United States might be influenced by changes in the tax structure. They calculated the share of Adjusted Gross Income (AGI) accruing to the top 0.5% of taxpayers and found that the estimated time series was consistent with a significant behavioural response to falling tax rates, particularly following the Tax Reform Act of 1986.

Following on the Feenberg and Poterba (1993) study, Feldstein (1995) pioneered the use of panel data to estimate the ETI in the United States. The author used a panel of tax returns and the the Tax Reform Act of 1986 to identify the ETI. Using a tabulated difference-in-differences methodology, Feldstein (1995) generated large ETI estimates, ranging from one to three in alternative specifications. Using Feldstein's (1995) approach, Moffitt and Wilhelm (2000) found elasticities of AGI around the 1986 tax reform ranging from 1.76 to 1.99.

Subsequent research has focused mainly on the use of panel data in the tradition of Feldstein (1995) but has also attempted to address some of the econometric issues raised above, including mean reversion and/or the existence of secular income trends.

Auten and Carroll (1999) included base year income controls, as well as controls for region and occupation, in a two-stage least squares regression specification in an attempt to account for mean reversion and the possible divergence in the income distribution, and reported an elasticity estimate of around 0.6. Using a similar approach to Auten and Carroll (1999), Moffitt and Wilhelm (2000) found tax elasticity estimates that range from 0.35 to 0.97 using alternative instruments.

However, the included controls likely failed to adequately control for mean reversion. Both studies only used two years (i.e. pre- and post-reform) and as such the results are particularly sensitive to mean reversion. The 1986 tax reform reduced top marginal tax rates in the US which likely resulted in a downward bias in estimated elasticities in the presence of mean reversion. In fact, when including 1983 AGI as a further control, Moffitt and Wilhelm (2000) found that their elasticity estimates increased by between 0.3 and 0.5.

Gruber and Saez (2002) addressed some of the shortcomings in earlier studies by analysing behavioural changes over three-year intervals around both the 1981 and 1986 tax reforms. The authors included several alternative specifications of base-year income controls in an attempt to control for mean reversion and secular income trends in a robust fashion. For example, they included richer income controls in the form of splines in base year income to control for possible non-linearities in the widening of the income distribution. At 0.4, their estimated elasticity lies in the middle of the post-Feldstein range.

Using similar methods to Gruber and Saez (2002), Auten et al. (2008) investigated the Bush tax cuts of the early 2000s. The model includes a number of additional variables in an attempt to control for key taxpayer characteristics and mean reversion. Auten et al. (2008) estimated a taxable income elasticity in the base model of about 0.4, with estimates for other specifications and samples ranging from about 0.2 to 0.7. More recently, Singleton (2011) applied similar methods to the marriage penalty relief provision contained in the Economic Growth and Tax Relief Reconciliation Act (EGTRRA) of 2001 to identify the ETI and estimated a joint elasticity ranging from 0.2 to 0.3.

Gruber and Saez (2002)'s study was also one of the first to obtain elasticity estimates for both broad and taxable income.[15] At 0.12, the estimated elasticity for broad income was substantially smaller than the corresponding estimate for taxable income. The authors argued that the difference in estimated elasticities implied that much of the response of taxable income to changing tax rates worked through the availability of itemised deductions. This was confirmed by the fact that the estimated ETI is much larger for itemisers (i.e. those taxpayers who make use of itemised deductions) than non-itemisers.

Giertz (2007) came to a similar conclusion, but from a different angle. The author investigated the change over time in estimated elasticities and related this change to the availability of exemptions and deductions. Applying the methods of Gruber and Saez (2002) to larger panel data sets between 1979 and 2001, Giertz (2007) obtained ETI estimates that were much larger than the corresponding estimates for broad income. These estimates are consistent with the results from Kopczuk (2005) which suggested that the availability of deductions and exemptions matter in determining the ETI. Kopczuk (2005) noted that the fraction of taxpayers choosing to itemise was approximately 25% lower in the early 1990s compared to the mid-1980s, which accounted for lower ETI estimates for the later decade. This confirms the importance of the availability of deductions, exemptions, and exclusions in the measurement of the income response to changing tax rates.

In general, estimated values of the ETI were lower in the 1990s (identified using the 1990 and 1993 tax reforms) than in the 1980s (identified using the 1981 and 1986 reforms). Apart from the availability of deductions and exemptions, there are two broad explanations for this pattern of results (Saez et al., 2012). The first is that there is no reason to expect that the ETI will be constant over time. Leading proponents of this view are Slemrod and Kopczuk (2002) who argue that the ETI is not a structural parameter, but is in fact a function of individual preferences, the breadth of the tax base, and the the efficiency of tax enforcement, among other factors (Kopczuk (2005) and Giertz (2007), among others, have found evidence in support of this hypothesis). The second explanation, as proposed by Giertz (2007), is that, despite the inclusion of several controls, the models still fail to adequately control for exogenous income trends. In particular, an increase in income inequality could result in an upward bias in ETI estimates amid falling tax rates, and vice versa when rates increase. Additionally, most models fail to adequately control income shifting between corporate and personal income, which could also lead to biased ETI estimates.

In fact, while the studies listed above attempted to control for mean reversion and secular income trends in a more nuanced way, they likely still underestimated the elasticity of taxable income. Weber (2014) showed that mean reversion prevents most estimators employed in the literature from obtaining consistent estimates of the ETI. Before estimating the ETI empirically, Weber (2014) examined a wide range of instruments, both theoretically and empirically, in order to determine which instruments will in fact be exogenous. The author used the Michigan IRS Tax

[15] Broad income is defined as income before deductions.

Panel data set for the years 1979 to 1990 to derive a consistent baseline ETI estimate of around 0.86, with the corresponding elasticity of broad income estimated at 0.475, both of which are somewhat higher than earlier estimates.

Most of the post-Feldstein literature focuses on legislated tax changes. However, several studies also investigated unlegislated changes and their impact on taxpayer behaviour. Saez (2003) used tax increases resulting from 'bracket creep' between 1979 and 1981 to estimate the ETI. 'Bracket creep' was a contentious issue in the late 1970s in the US, with tax brackets remaining fixed in nominal terms despite inflation measuring in excess of 10% per annum. Saez used an instrumental variable approach, including base-year income controls and dummies for filing and itemization status in the regression framework, and found a statistically insignificant overall ETI estimate of 0.31. However, when itemisers were considered separately, the estimate rose substantially, again highlighting the fact that itemisers are more responsive to tax changes.

Finally, Saez (2010) used the phenomenon of bunching around kink points in the tax schedule to estimate the compensated elasticity of taxable income. In the standard model, the elasticity will be proportional to the amount of bunching at a particular kink (Saez et al., 2012). Saez (2010) found evidence of bunching at the threshold of the first tax bracket, especially in the 1960s, but found little evidence of bunching at other kink points in the tax schedule, even where the jumps in marginal tax rates were substantial.

ETI in other countries

While the bulk of research on the ETI has focused on the United States, some studies have investigated Canada and a select number of European countries. Importantly, given the fact the ETI depends critically on the specific features of the tax system under consideration (such as the definition of the tax base, opportunities for tax avoidance and/or evasion, and the enforcement regime), there is little reason to expect that the ETI will be uniform across countries.

The 1988 Canadian tax reform raised statutory marginal rates for the two lowest income groups and lowered them for those falling in the top nine brackets, while broadening the tax base by either eliminating deductions and exemptions or converting them to non-refundable tax credits (Saez et al., 2009).

Sillamaa and Veall (2001) use the 1988 Canadian tax reform to identify the ETI for Canada. Using a panel of taxpayers who filed in both 1986 and 1989 and employing similar methods to Auten and Carroll (1999), the authors estimated an ETI of 0.14 for those aged 25 to 61 and 0.27 for those older than 64. The corresponding estimates for broad income were 0.25 and 0.29, respectively. Similar to results for many studies in the United States, estimated elasticities were much higher for high-income earners. In contrast to the usual findings based on US data, broad income elasticities were found to be much higher than taxable income elasticities. One reason might be because deductions are much more limited in Canada than in the US. Given the importance of the availability of itemised deductions in determining the size of estimated elasticities, the lack of available deductions might account for the difference.

Saez and Veall (2005) used income-shares methods in the vein of Feenberg and Poterba (1993) to analyse the effect of income taxation on high-income earners in Canada. They estimated elasticities of 0.83 and 0.96 for the top 1% and top 0.1% of taxpayers, respectively. When they included additional income controls, the elasticity estimates fell to 0.48 and 0.30.

In the United Kingdom, several studies have investigated the response to the Thatcher tax cuts. During the Thatcher administration, the top marginal tax rate fell from 83% 1978 to 40% in 1988. Dilnot and Kell (1988) analysed the 1979 rate cut and found that the share of tax revenue collected from the top 1% of income earners stayed constant between 1978 and 1985 despite the large drop in the top marginal rate. The authors argued that this implied that income accruing to the top 1% must have increased following the rate cut. Brewer et al. (2010) analysed time series information for the top 1% of income earners for the period between 1962 and 2003. They found that the top 1% income share in the UK fell steadily until 1978 and started increasing precisely in 1979. Time series regressions produced significant elasticity estimates of around 0.5, even when controlling for base year income and changes in inequality.

Using a method similar to Gruber and Saez (2002), Kleven and Schultz (2014) used a panel of tax return data for the period 1980 to 2003 to estimate the behavioural responses to the various income tax reforms implemented in Denmark over the sample period. In contrast to other studies, they had access to the full universe of Danish tax filers, generating a very large longitudinal dataset. They found modest population-wide elasticities (in the order of 0.2 to 0.3). However, similar to other studies, they showed that estimated elasticities were two to three times larger for high-income earners.

Chetty et al. (2011) built on the method developed by Saez (2001) and used the bunching approach to estimate the ETI for Denmark. They developed a new framework in which the presence of adjustment costs reduce the short-run behavioural response to changing tax rates. Additionally, the presence of adjustment costs leads to substantial heterogeneity in the estimated short-run behavioural response under different reform scenarios. The authors point out that it is important to take the heterogeneous short-run responses into account when estimating long-run elasticities.

Selén (2002) and Hansson (2007) both used Sweden's 1991 tax reform to identify the ETI. Both studies employed difference-in-differences methodologies based on Feldstein (1995) and Moffitt and Wilhelm (2000). However, Selén (2002) also employed a number of variations in the vein of Gruber and Saez (2002). Hansson (2007) reported ETI estimates for Sweden that ranged from 0.37 to 0.43, similar to other international studies. Selén (2002) reported estimated ETIs that were generally between 0.2 and 0.4, but reported an ETI of 0.53 when restricting the analysis to the top two income tax brackets.

Gottfried and Schellhorn (2004) followed the approach in Gruber and Saez (2002) to estimate the taxable income responses to the German tax reforms of 1990 but used only two years, 1988 and 1990. They reported a compensated elasticity of 0.58. Importantly, using only two years might compromise identification in the presence of mean reversion and/or changes in income inequality.

Atkinson and Leigh (2008) analysed the top 1% income shares in New Zealand from 1921 to 2005. They regressed the top 1% income share on one-year lags of the net-of-tax rate and several controls, finding an overall ETI estimate of 0.41.

Other studies focused on Germany (Gottfried and Schellhorn, 2004), France (Piketty, 1999), Finland (Pirttilä and Selin, 2006), Poland (Kopczuk et al., 2012), New Zealand (Atkinson and Leigh, 2008), and Russia (Gorodnichenko et al., 2009), to name a few. In general, ETI estimates are in the 0.2 to 0.8 range.

Tax research in South Africa has focused on the impact of specific tax measures and the welfare implications of the broader tax system. Examples include research on the impact of the employment tax incentive, the impact of introducing a negative income tax, welfare implications of specific tax allowances/deductions, the impact and incidence of value added tax (VAT), and numerous studies investigating different aspects of corporate taxation.[16] However, very little work has been done in the South African context with respect to the estimation of the elasticity of (personal) taxable income - the main focus of this paper. Van Heerden (2013) estimated implied personal income tax elasticities using macro data and found elasticities of between 0.38 and 0.79

[16]See Ebrahim et al. (2019) for a review of tax research in South Africa.

for the various income groups under consideration. Due to lack of access to microeconomic data, the author used macro time series to calculate the revenue-maximising and growth-maximising tax rates, which were then used to calculate the taxable income elasticity according to the Scully model (Scully, 1991).

2.3 Estimating the ETI for South Africa

As mentioned in the literature review above, much of the international literature uses legislated tax reforms to identify the elasticity various income measures, including taxable and broad income. Notwithstanding the fact that the ETI varies between countries depending on the nature of the tax system, there is no empirical consensus with respect to the size of the elasticity - even within specific countries.

According to Saez (2003), two reasons might explain this lack of consensus. First, in addition to introducing changes in tax rates, most tax reforms also change the definition of taxable income. In this case, comparing pre- and post-reform incomes might lead to biased elasticity estimates given the lack of a consistent definition of taxable income. Second, most studies rely on a comparison between high- and low- or middle-income taxpayers. The former often experience large tax rate changes after any given tax reform, while the latter experience little or no change in marginal tax rates.

The above considerations suggests that the research design for estimating behavioural responses to changing tax rates should meet two conditions. First, the tax change under consideration (i.e. the reform) should ideally affect only marginal tax rates and not introduce significant definitional changes. Second, the tax change should differently affect groups of taxpayers that are comparable in terms of incomes and other economic characteristics (Saez, 2003).

Taking these factors into account and considering the fact that there was no large legislated tax reforms in South Africa over the sample period, Saez (2003) is followed in utilising the phenomenon of 'bracket creep' to estimate the elasticity of taxable income. 'Bracket creep' introduces exogenous variation in tax rates since a taxpayer near the top end of an income tax bracket might graduate to the next bracket, even if their real income does not change, in the presence of inflation. This is especially true if nominal income tax brackets are not fully adjusted for inflation (so-called fiscal drag). In contrast, taxpayers at the bottom end of the relevant tax bracket are unlikely to experience an increase in marginal rates.

In practice, the method compares changes in the incomes of taxpayers near the top end of a bracket to those taxpayers at the bottom end of the bracket using tax return data. Importantly, 'bracket creep' does not affect the definition of taxable income. Additionally, this strategy compares groups of taxpayers that are closely related in terms of income levels and economic characteristics, thereby satisfying the conditions set out above.

Two limitations of the approach should be mentioned. First, the tax rate changes induced 'bracket creep' are relatively small compared to other tax reforms across the decades. Second, because 'bracket creep' is not a legislated tax change, taxpayers might not be aware of the effect that this change might have on their after-tax income. As a result of these two factors, the behavioural response to 'bracket creep' might be muted. This suggests that ETI estimates obtained using 'bracket creep' reflect a lower bound for the behavioural response to changing tax rates.

Keeping these caveats in mind, this section estimates the ETI for South Africa using the 'bracket creep' approach as implemented in Saez (2003).

2.3.1 South African Personal Income Tax System and Tax Reforms

Income tax in South Africa was first introduced in 1914. Normal income taxes are levied on all individuals in the form of an annual tax that is calculated by applying predetermined rates to an individual's taxable income. Taxable income is defined as gross income (salary and wage income, business income, interest income, and sundry income such as dividend income and annual payments, including bonuses) less exempt income and allowable deductions.[17]

Since 1994, the personal income tax system has undergone numerous changes. Against the backdrop of a rising personal income tax burden in the 1980s, the Katz Commission was tasked with a comprehensive review of the South African tax system. The commission's first interim report was released in 1994 (Katz Commission, 1994). Based on the recommendations of the Katz Commission (and other role-players, including the National Treasury), the South African income tax system was changed in many respects over the last 20 years. For instance, the number of personal income tax brackets was reduced from 10 to 6; the child rebate was scrapped; the individual is now the unit of taxation; the primary rebate was increased annually to compensate for inflation and to retain progressivity; capital gains tax was introduced; and the secondary tax on companies (STC) was replaced by a dividends tax.

Several implications of the (changing) tax code described above are worth noting in the context of the present study. Firstly, the sample used in this study does not include any major PIT tax reforms. Between the 2008/9 and 2012/13 tax years, marginal tax rates remained unchanged, while the reforms that were implemented (including the switch from the STC to the dividends tax and the introduction of the tertiary rebate) were insignificant in the sense that they are unlikely to have induced a major behavioural response on the part of individual taxpayers.

The lack of major tax reforms complicates the identification of the ETI. During the sample period in question, there was no large, policy-induced variation in marginal tax rates of the kind that is often used to identify and estimate the ETI. As such, Saez (2003) will be followed in using the phenomenon of 'bracket creep' to identify the ETI.

Over our sample period, the National Treasury adjusted individual tax brackets in order to compensate for the effects of inflation.[18] The extent to which official bracket adjustments compensate for inflation depends critically on the measure of inflation that is used. Popular inflation measures include the consumer price index (CPI) and the GDP deflator. However, these measures might underestimate the extent to which nominal incomes change from year to year. If nominal wages increase in excess of official inflation measures, then taxpayers near the top end of an income tax bracket might still be pushed into the next bracket, despite the announced bracket adjustments. This is particularly true in the case of South Africa where, in the past, wage adjustments have often been in excess of consumer price inflation.

Table 2.1 shows the average effective bracket adjustment for each tax year in question along with two inflation measures (based on the CPI and the GDP deflator) and a measure of economy-wide wage inflation.[19] Apart from 2008/09, bracket adjustments were generally in line with inflation as measured by the CPI and GDP deflator. However, as mentioned above, when studying the

[17] In the case of South Africa, exemptions include, among others, interest income earned from a South African source up to a certain threshold. Itemised deductions include, among others, current and arrear pension fund contributions, current and arrear retirement annuity fund contributions, medical and disability expenses, and donations.

[18] National Treasury uses expected CPI inflation for the following fiscal year as a base for the bracket adjustment calculations, tailoring the adjustment according to budgetary requirements. For example, in the February 2017 budget, the National Treasury forecast CPI inflation of 6.4% in 2017, but tax brackets were only adjusted by 1% in 2017/18 due to additional revenue requirements.

[19] The measure of the economy-wide wage rate is calculated as total compensation of employees as published in the SARB Quarterly Bulletin divided by total employment as published in Statistics South Africa's Quarterly Labour Force Survey.

Table 2.1: Bracket adjustment and inflation

Tax year	Average bracket adjustment	CPI inflation	GDP deflator	Economy-wide wage rate
2008/09	8.4%	9.9%	8.9%	7.7%
2009/10	7.7%	7.1%	7.5%	11.6%
2010/11	5.3%	4.3%	6.3%	14.8%
2011/12	6.1%	5.0%	6.5%	7.9%
2012/13	6.5%	5.3%	5.3%	6.2%

Source: National Treasury, Statistics South Africa, South African Reserve Bank. Inflation rates calculated as year-on-year % changes in CPI, the GDP deflator, and the total economy-wide wage rate.

phenomenon of 'bracket-creep' the relevant inflation measure is nominal wage inflation. When comparing average bracket adjustments to economy-wide wage inflation, it is noticeable that, apart from 2008/09 and 2012/13, bracket adjustments were not in line with nominal wage inflation. This suggests that a significant proportion of taxpayers likely migrated to higher tax brackets and, as a consequence, faced a higher marginal tax rate in the following tax year. It is this phenomenon of 'bracket creep' that will be used to identify the ETI.

As mentioned in Section 2.2.3, taxpayers might not be fully aware of small changes to the tax code and, as such, any estimated behavioural response in reaction to such changes will be muted. While income tax brackets were not fully adjusted for wage inflation, they did not remain constant in nominal terms as was the case in the US in the period under consideration in Saez (2003). As a result, there was relatively little variation in marginal tax rates between 2009 and 2013. This implies that the estimated ETI in Section 2.3.4 likely underestimates the true behavioural response to a change in marginal tax rates in the case of South Africa.

Finally, it is worth noting that the tax code described above (i.e. graduated income tax schedule, allowable deductions, low-income tax rebates, exemptions, etc.) ultimately results in a highly progressive income tax system. The progressive nature of the South Africa tax code implies that most of the action in terms of the behavioural response of individual taxpayers to changing marginal tax rates will be concentrated at the top of the income distribution. A number of empirical studies have confirmed this fact internationally, with less evidence of any response for the low, middle and upper-middle income classes (Saez et al., 2012). This suggests that it might be useful to disaggregate the estimated aggregate ETI by income group in order to identify possible differentiated behavioural responses. Such differentiated responses have implications for the formulation of optimal tax policy.

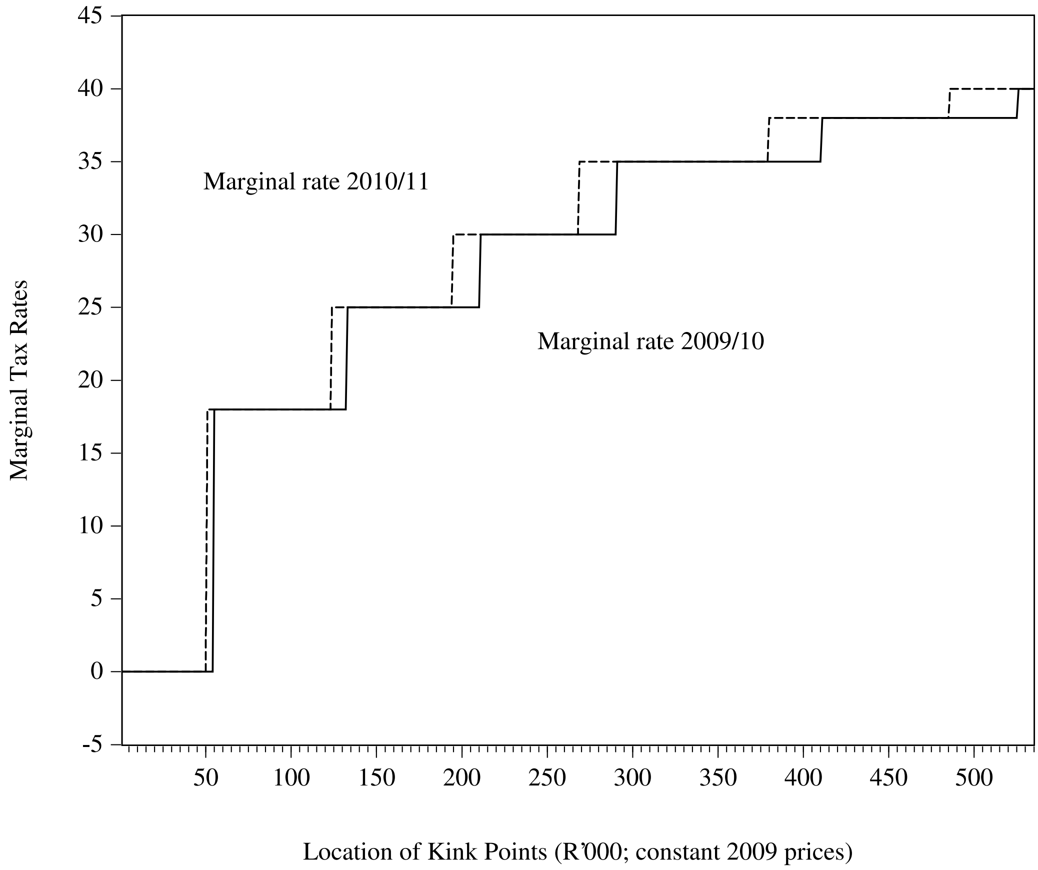
2.3.2 'Bracket Creep', Data and Descriptive Statistics

'Bracket Creep'

As mentioned above, the sample period in question did not contain any large tax reforms of the kind that is often used to identify and estimate the ETI. We will follow Saez (2003) in using the phenomenon of 'bracket creep' to identify the ETI.

Saez (2003) examines behavioural responses to tax increases resulting from 'bracket creep' between 1979 and 1981 for the US. During those years, tax brackets were fixed in nominal terms despite inflation measuring in excess of 10% per annum. This resulted in taxpayers graduating to higher income brackets despite real income remaining constant (or even declining) between years.

Figure 2.1: Shift in marginal tax rates between 2009/10 and 2010/11



In contrast, in South Africa, nominal tax brackets have regularly been adjusted. However, these adjustments have not always fully accounted for the effects of inflation. By not fully adjusting for the effects of inflation, tax revenues can increase automatically as taxpayers graduate to higher income tax brackets.

The extent to which bracket adjustments compensate for inflation depends critically on the measure of inflation that is used. Popular inflation measures include the consumer price index (CPI) and the GDP deflator. However, these measures might underestimate the extent to which nominal incomes change from year to year. As such, we follow Gruber and Saez (2002) in calculating an inflation measure based on the average growth of gross or broad income for each of the years in the sample. This measure more accurately reflects the actual change in nominal incomes from year to year. Should official bracket adjustments not fully compensate for (above inflation) nominal income growth, the 'bracket creep' effect will be more pronounced.

Figure 2.1 displays the effect of the chosen inflation measure on marginal tax rates between 2009/10 and 2010/11.[20] Marginal rates as a function of before-tax *real* income is plotted for the 2009/10 (solid line) and 2010/11 (dotted line) tax years. If taxable income stays constant in *real* terms, then some taxpayers will face a higher marginal rate in year two. Apart from the lowest income bracket, the changes in marginal rates are not very large (between 2% and 5%). This is a far cry from the large reforms often studied in the literature.[21] However, the 'bracket creep' phenomenon does provide for some variation in tax rates, even in an environment where

[20]Our measure of inflation was largest across this pair of years, resulting in a clear illustration of the 'bracket creep' effect.

[21]For example, the 1986 Tax Reform Act in the US led to a decrease from 50% to 28% in marginal rates for very high income earners.

there were no legislated changes in marginal tax rates.

Data and Descriptive Statistics

The analysis presented here uses confidential tax return data, made available for research purposes by SARS and the National Treasury. The available sample runs from 2008 to 2012.[22] The full dataset contains most items found on individual Employee Tax Certificate (IRP5/IT3(a)) and/or Income Tax Return (ITR12) forms. This includes information on various aspects of personal income taxation, including information on labour, business and investment income, deductions, exemptions and allowances, taxable income, and total tax liability. The full dataset also contains information on assessed taxes, i.e. income tax returns that were processed and assessed by SARS.[23]

It was decided to focus the analysis on those taxpayers who submitted tax returns between 2008 and 2012 that were, in turn, assessed by SARS. Importantly, focusing on assessed taxes alone significantly reduces the number of observations available for the analysis. Between 2007 and 2011, individual taxpayers in South Africa were not liable to file a tax return if their employment income was less than R120 000 per annum, provided that the income was derived from employment only (i.e. labour income as recorded on the IRP5 form). This limit was increased to R250 000 in 2012.

International evidence points to the fact that most of the action in terms of behavioural responses to changing marginal tax rates is concentrated in higher income groups and among those taxpayers with itemised deductions. Given that the assessed tax database includes only those individuals with relatively high personal income levels and/or itemised deductions, focusing on this dataset will still allow us to obtain an estimate of the ETI that reflects the broad behavioural response of the South African taxpayer to changing marginal tax rates. Additionally, given the relatively small changes in marginal rates induced by the 'bracket creep' phenomenon, it is unclear whether those individuals with lower (single source) income and no itemised deductions would have responded by altering their labour supply decisions.

Finally, according to official statistics published by SARS, assessed taxes on average made up over 85% of total personal income taxes between 2008 and 2012. This suggests that any behavioural change for this group of taxpayers will have significant revenue implications.

To facilitate an estimation of the ETI, a balanced panel was constructed using the assessed dataset by selecting only those individuals present in each of the years in the sample, resulting in just over 3 million observations per year.[24] Table 2.2 presents means and standard deviations of the relevant income data (in real terms) for the constructed panel over the entire sample period (2008 - 2012).

Two types of definitions were used for income: gross or broad income, and taxable income. Broad income is an extensive definition of income that is consistent across all the years in the

[22] In truth, the sample runs from the 2008/09 tax year to the 2012/13 tax year. In South Africa, the tax year runs from 1 March to 28 February of the following year. For notational convenience, the paper will refer only to the *calendar* year which comprises the largest proportion of the relevant tax year, i.e. 2008/09 becomes 2008, 2009/10 becomes 2009, etc.

[23] Several other datasets are available that could feasibly be used to extract elasticity estimates, including the National Income Dynamics Study (NIDS) datasets and the various labour force surveys published by Statistics South Africa. This is particularly true for the estimation of labour supply elasticities. Having said that, the dataset used in this chapter provides for a greater degree of accuracy in terms of income and tax figures given that it is based on primary records, while the coverage in terms of number of individuals/households is also far larger, providing for a holistic view of the taxpaying population.

[24] Before creating the panel, the dataset was cleaned by removing one outlier, as well as selecting only on those individuals with recorded values for gross and taxable income. No transformations were applied.

Table 2.2: Summary statistics: Balanced panel
(2008-2012; constant 2008 prices)

	Mean	S.D.
Broad income	R225 557	R366 784
Normal income	R190 364	R238 024
Other income#	R77 498	R447 586
Investment income#	R54 017	R309 056
Business income#	R87 914	R333 824
Capital gains income#	R102 304	R818 943
Taxable income	R202 274	R351 935
Itemisers	83%	
Number of observations	15 041 970	

#Statistics for other income, investment income, business income, and capital gains income were calculated by only taking into account those individuals with recorded values for the respective income sources.

sample. It includes most of the items that are summed to arrive at total income (as recorded on IRP5/IT3(a) and ITR12 forms), namely wage income, investment income, business income, fringe benefits, allowances, etc.[25] International literature is followed in excluding capital gains income from the broad income calculation due to the special tax treatment afforded to capital gains (see Section 2.2.3). Taxable income is defined as broad income less exemptions and other allowable deductions.

According to Table 2.2, the average broad income in the sample equals about R225 000 and average taxable income equals around R202 000, measured in constant 2008 values. Eighty-three percent of the individuals in the dataset recorded itemised deductions.

As mentioned above, our inflation measure is based on the average growth of broad income for each of the years in the sample. Taking 2008 as the base year index (equal to 100), the incomes for years 2009 to 2012 have been deflated using the following indices: 109.61, 124.59, 137.70, and 150.52.

It should be noted that the choice of 2008/09 as base year might conceivably impact on the estimation given the fact that 2009 was the year in which the largest impact of the GFC was registered. Employment contracted sharply in 2009 and 2010, inflating the measure of the economy-wide measure of wage inflation presented in Table 2.1. That being said, the construction of the sample used in estimation negates some of this effect. As discussed above, the estimation sample includes only assessed taxpayers that submitted returns in each of the years in the sample. These individuals therefore remained employed, or earned income, across the sample period. Even when only considering this balanced panel, growth in broad income (the chosen inflation measure to construct the instruments below) averaged close to 11% per year over the sample period, significantly above the bracket adjustments detailed in Table 2.1. Therefore, while the choice of 2008/09 as base year might conceivably affect the results, the impact is lessened by the nature of the construction of the estimation sample.

2.3.3 Empirical Strategy

Following Gruber and Saez (2002), the empirical strategy is to relate changes in income between pairs of years to the change in marginal tax rates between the same pairs of years. The time length between year one (the base year) and year two can be one, two or three years. In

[25] A detailed description of the construction of the income measures is provided in Appendix A.

our basic specification, we follow Gruber and Saez (2002) and Feldstein (1995) in setting the time length equal to three years. Therefore, we relate year 2011 to year 2008, and year 2012 to year 2009. These two differences are stacked to obtain a single dataset of about 6 million observations. Given the fact that the identification strategy employed here relies on what is essentially unobserved tax rate changes, the time lag allows for a more complete behavioural response as taxpayers become aware of the tax implications of 'bracket creep'.

We use the basic model discussed in Section 2.2.1 to derive a regression specification. Recall that the basic model boils down to estimating e^c in Equation (2.2.3), repeated here for convenience:

$$\frac{dz}{z} = -e^c \frac{d\tau}{1-\tau} + \eta \frac{dR - zd\tau}{z(1-\tau)}$$

where z is real income, e^c is the compensated elasticity of taxable income, τ is the relevant marginal tax rate, η is the income effect, and R is virtual income. This equation displays the behavioural response in reported income induced by a small tax change. Following Gruber and Saez (2002), this equation can be estimated by replacing z by z_1 (year one income), dz by $z_2 - z_1$ (change in income between year 1 and year 2), dτ by $T'_2(z_2) - T'_1(z_1)$ (the change in marginal tax rates), and d$R - z$ by $[z_2 - T_2(z_2)] - [z_1 - T_1(z_1)]$ (the change in after-tax income).[26]

Using the log-log specification and replacing dz/z by $\log(z_2/z_1)$, $-\mathrm{d}\tau/(1-\tau)$ by $\log[(1-T'_2)/(1-T'_1)]$, and $(\mathrm{d}R - z\mathrm{d}\tau)(z(1-\tau))$ by $\log[(z_2 - T_2(z_2))/(z_1 - T_1(z_1))]$,the following regression specification is obtained:

$$\log(z_2/z_1) = e \log[(1-T'_2)/(1-T'_1)] + \eta \log[(z_2 - T_2(z_2))/(z_1 - T_1(z_1))] + \epsilon \qquad (2.3.1)$$

where e is the compensated elasticity parameter, η is the income effect parameter, z_i is *real* income in year i, T'_i is the marginal tax rate in year i and $T_i(z_i)$ is the tax liability in year i.

Ignoring the income effect for now (i.e. set $\eta = 0$), we see that the term capturing the tax rate change $\log[(1-T'_2)/(1-T'_1)]$ is correlated with ϵ because a positive shock to income (i.e. $\epsilon > 0$) will generate a mechanical increase in the marginal rate due to the progressive nature of the income tax system. Therefore, an OLS estimate of (2.3.1) will produce a biased estimate of the behavioural elasticity.

Gruber and Saez (2002) and Saez (2003), among others, is followed in building an instrument for this variable by computing T'_p, the predicted marginal tax rate in year two had individual *real* income remained unchanged between year one and two. That is, $T'_p = T'(z_p)$ where z_p is predicted taxable income in year 2, which is taxable income in year 1 expressed in year 2 Rands. The natural instrument for $\log[(1-T'_2)/(1-T'_1)]$ is therefore $\log[(1-T'_p)/(1-T'_1)]$, or the predicted change in the log net-of-tax rate if real income does not change between year one and year two.

Columns (1) and (4) in Table 2.3 provide information on the value of the instrument for each pair of years in our sample for the six different tax brackets (defined based on base year taxable income).[27] By construction, the instrument is negative for a tax rate increase and positive for a tax rate cut. Over both pairs of years and across all income groups the values are negative, reflecting the fact that 'bracket creep' pushed most taxpayers into higher tax brackets. The value for the instrument is zero in the top tax bracket, suggesting that those who were in the top bracket in year one remained there in year two. The fact that there are no positive values for the instrument suggests that nominal tax brackets were not fully adjusted for (our measure of)

[26] Here, $z(1-\tau)$ is approximated by $z - T(z)$

[27] Baseline results are presented for the three-year difference case. The implications of different lengths of differences are discussed in Section 2.3.5.

Table 2.3: Variation in after-tax shares and mean reversion in income

		2008-2011			2009-2012		
		Instrument	Difference in log of taxable income	Difference in log of broad income	Instrument	Difference in log of taxable income	Difference in log of broad income
		(1)	(2)	(3)	(4)	(5)	(6)
Tax Bracket#	1	-0.01	0.17	0.19	-0.02	0.17	0.12
		[0.03]	[0.71]	[0.66]	[0.03]	[0.69]	[0 .62]
		1 218 858	1 218 858	1 218 858	1 156 133	1 156 133	1 156 133
	2	-0.02	-0.04	0.01	-0.02	0.00	-0.01
		[0.03]	[0.40]	[0.36]	[0.03]	[0.41]	0.36
		861 336	861 336	861 336	877 650	877 650	877 650
	3	-0.03	-0.10	-0.05	-0.03	-0.05	-0.06
		[0.04]	[0.45]	[0.40]	[0.04]	[0.45]	[0.40]
		367 613	367 613	367 613	394 910	394 910	394 910
	4	-0.02	-0.15	-0.11	-0.02	-0.09	-0.09
		[0.02]	[0.49]	[0.43]	[0.02]	[0.49]	[0.43]
		254 070	254 070	254 070	270 487	270 487	270 487
	5	-0.02	-0.18	-0.15	-0.02	-0.13	-0.13
		[0.02]	[0.52]	[0.46]	[0.02]	[0.51]	[0.46]
		121 788	121 788	121 788	120 994	120 994	120 994
	6	0.00	-0.29	-0.26	0.00	-0.21	-0.21
		-	[0.65]	[0.59]	-	[0.63]	[0.58]
		184 729	184 729	184 729	188 220	188 220	188 220

#Taxpayers grouped into tax brackets based on base year taxable income (1 = bottom bracket, 6 = top bracket). Means, standard deviations (in square brackets), and number of observations are reported. Taxable income and broad income expressed in constant 2008 prices.

inflation over the sample period. It is also important to note that while there is little variation in the mean value of the instrument between income groups (or tax brackets), there is substantial heterogeneity within groups, as illustrated by the relatively large standard deviations.

According to Gruber and Saez (2002), running an instrumental variables (IV) regression of (2.3.1) might also lead to a biased estimate of the elasticity if ϵ is correlated with z_1. This relates to the earlier discussion on mean reversion and a changing income distribution. In the presence of mean reversion, high incomes in year one tend to be lower in following years, resulting in a negative correlation between ϵ and z_1. On the other hand, should the income distribution widen, there will be a positive correlation between ϵ and z_1. Importantly, if ϵ is correlated with z_1, then the instrument (which is also a function of z_1) will also be correlated with the error term, producing biased estimates. It is for this reason that many studies in the literature follow Auten and Carroll (1999) in including lagged income as a control, either in a simple way by including $\log z_1$ or in a richer way by including polynomials or splines in year one incomes.

There is definite evidence of mean reversion in the sample, both in terms of taxable income and broad income. Columns (2)-(3) and (5)-(6) in Table 2.3 shows the mean values of the dependent variables for each pair of years in the sample for the different income groups. There are high and positive values for the dependent variable at the low end of the distribution, presenting clear evidence of mean reversion. Similarly, the change in income is, in general, negative for higher income earners, suggesting that high base-year incomes are followed by lower incomes in year 2. For this reason, several base year income controls are included in the final regression specification.

Turning to the income effect, the term $\log[(z_2 - T_2(z_2))/(z_1 - T_1(z_1))]$ will also be correlated with ϵ for the same reasons discussed above. However, in much of the literature, the income effect is assumed away (i.e. $\eta = 0$) since those studies that do estimate income effects often find them to be small and insignificant. In the current study, there is an additional motivation for omitting income effects from the base specification. In the presence of 'bracket creep', the income effect term affects those individuals who experience a change in marginal rates (treatments) and those individuals who do not experience a change in marginal rates (controls) in approximately the same way. Therefore, Saez (2003) argues that this additional income effect can be incorporated into the error term.

To see why, recall that $dR - zd\tau$ in equation 2.2.3 is the change in after-tax income due to the tax change for a given before-tax income z. Because of 'bracket creep', this quantity is piece-wise linearly but continuously increasing in income, thus affecting the treatment and control groups in approximately the same way. Intuitively, at any given kink in the tax schedule 'bracket creep' results in similar increases in the tax liability of treatment and control groups. However, the change in marginal tax rates is different, with the treatment group experiencing and increase in the marginal rate while marginal rate for the control group remains unchanged. As a result, the difference in the behavioural response between the treatment and control groups is almost exclusively due to pure substitution effects. This implies that, in this framework, the estimated elasticity e when $\eta = 0$ is, in fact, equal to the compensated elasticity, e^c, the parameter of interest. Therefore, as in Saez (2003), this additional income effect term can be incorporated in the error term. The dependence of this error term on income is controlled for by functions in $taxinc_1$.

The precise regression framework is the following:

$$\begin{aligned}\log(z_2/z_1) = \alpha_0 + e^c \log[(1-T_2')/(1-T_1')] + \alpha_1 \log z_1 + \alpha_2 f(taxinc_1) \\ + \sum_{i=1}^{10} \alpha_{3i} SPLINE_i(z_1) + \sum_j \alpha_{4j} YEAR_j + \beta item + \epsilon\end{aligned} \quad (2.3.2)$$

where z_i is *real* income in year i (either taxable income or broad income), T_i' is the marginal rate in year i, and e^c is the parameter of interest, i.e. the compensated elasticity. $YEAR_j$ denotes base year dummies and *item* is a dummy variable for being an itemiser in year one (i.e. individuals with recorded itemised deductions). $SPLINE_i$ is a ten-piece spline in base year income (included as control in some specifications), while $f(taxinc_1)$ are smooth functions in (nominal) base year income (polynomial terms in $taxinc_1$). Polynomial terms are added until the elasticity estimate is stabilised (two terms are sufficient in most cases).

The dataset is constructed by stacking differences in income across individuals and years. Equation (2.3.2) is then estimated by simple 2SLS, the first stage being:

$$\begin{aligned}\log[(1-T_2')/(1-T_1')] = \log[(1-T_p')/(1-T_1')] + \theta_1 \log z_1 + \theta_2 f(taxinc_1) \\ + \sum_{i=1}^{10} \theta_{3i} SPLINE_i(z_1) + \sum_j \theta_{4j} YEAR_j + \gamma item + \epsilon\end{aligned} \quad (2.3.3)$$

where $\log[(1-T_p')/(1-T_1')]$ is used as an instrument for $\log[(1-T_2')/(1-T_1')]$. The first stage of the regression is very strong, with the associated F-statistics always in excess of the relevant critical value.[28]

Finally, due to the fact that observations from two pairs of years were stacked to form the dataset, multiple observations are used on the same individuals. In a standard 2SLS framework, any individual-specific correlation in how income changes over time will result in biased standard error estimates. As such, all reported standard errors are corrected for intra-personal correlation.

[28] First stage results reported in Appendix A.

2.3.4 Basic Results

The basic results from the 2SLS regressions are reported in Table 2.4 (standard errors in parentheses). The table has eight columns, expressing three alternative methods for dealing with mean reversion and/or income distribution changes for the two income concepts. In columns (1) and (5), no controls are included. In columns (2) and (6), log income is included, as in Auten and Carroll (1999), among others. Columns (3) and (7) include polynomial terms in base year income as additional controls, as in Saez (2003). Importantly, there is no reason to expect that the two main sources of bias in estimating the ETI (mean reversion and income distribution changes) operate linearly, particularly in combination with each other. As such, following Gruber and Saez (2002), a final specification includes richer base period income controls in the form of a ten-piece spline in base year income in attempt to address the possible non-linearity. The results are recorded in columns (4) and (8) in Table 2.4.

Results are presented for both broad and taxable income. All regressions are weighted by income to reflect the relative contribution to total revenue, while at the same time facilitating the analysis of optimal taxation.[29]

As expected, the estimated elasticities display substantial sensitivity to the type in income controls included in the regression. For the models in Table 2.4 which exclude any income controls, large and, in the case of taxable income, wrong-signed elasticity estimates were obtained. However, when including log income as a control, the results change dramatically. For broad income, the elasticity falls to 0.17, while for taxable income, the elasticity becomes a positive 0.30. This estimate lies close to the mid-point of the post-Feldstein literature. Log income itself has a highly significant negative coefficient, highlighting the importance of controlling for mean reversion in the model set-up. Coefficients on the polynomial terms in the base year income, while small, are highly significant. Including the polynomial terms results in slightly smaller elasticity estimates.

The first set of models assumes that any change in the income distribution is a simple linear function of lagged income. This assumption can be weakened by including a ten-piece spline in lagged income. The estimated coefficients are all significant, suggesting that there is some evidence of non-linearity in the change in income distribution. Including the spline results in only a small change to the elasticity in taxable income (up to 0.31), but a more significant change in the case of broad income (up to 0.24). For both broad and taxable income, the splines are highly negative at the bottom of the income distribution. This could be indicative of worsening income prospects for low-income groups over this sample period. The coefficients display a high degree of non-linearity throughout the rest of the income distribution.

It is clear from the results that there are substantial (and statistically significant) differences between the elasticity estimates for broad and taxable income. There are two sources of difference here. The first is purely mechanical - broad income has a larger base so that any response will result in a smaller elasticity. The second, which has been referred to above and within the ETI literature, is behavioural. Taxable income includes itemised deductions and exemptions, which might respond to changes in taxes. This effect is clearly demonstrated when looking at the estimated coefficient on the itemiser dummies in Table 2.4. The coefficients are statistically significant and positive across all specifications, suggesting that a large share of the behavioural response to changing marginal tax rates takes place through itemised deductions.

Finally, the critical values reported in the final two rows of Table 2.3.4 suggest that we can reject the null of exogeneity with respect to the instrumented variable, namely

[29] As discussed in Gruber and Saez (2002) and Saez et al. (2012), the important parameters for the analysis of optimal taxation and deadweight burden are the elasticities weighted by income because the income response to a change in marginal rates is proportional to the elasticity times the income level.

Table 2.4: Basic elasticity results

	Taxable Income				Broad Income			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
e^c	-1.820***	0.304***	0.262***	0.314***	1.764***	0.167***	0.139***	0.235***
	[0.053]	[0.038]	[0.019]	[0.059]	[0.048]	[0.034]	[0.018]	[0.055]
item	0.008**	0.105***	0.097***	0.101***	-0.017***	0.096***	0.084***	0.092***
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.004]	[0.003]	[0.003]
$\log(z_1)$		-0.190***	-0.161***			-0.184***	-0.155***	
		[0.006]	[0.006]			[0.005]	[0.005]	
$taxinc_1$			-1.62e-08**				-1.66e-0.8***	
			[5.17e-0.9]				[4.74e-0.9]	
$taxinc_1^2$			2.22e-17**				2.26e-17**	
			[8.26e-18]				[7.54e-18]	
Spline 1^{st} decile control				-0.704***				-0.684***
				[0.003]				[0.003]
Spline 2^{nd} decile control				-0.133***				-0.059***
				[0.004]				[0.004]
Spline 3^{rd} decile control				-0.105***				-0.127***
				[0.012]				[0.010]
Spline 4^{th} decile control				-0.183***				-0.161***
				[0.013]				[0.013]
Spline 5^{th} decile control				-0.189***				-0.122***
				[0.015]				[0.009]
Spline 6^{th} decile control				-0.069***				-0.110***
				[0.020]				[0.013]
Spline 7^{th} decile control				-0.173***				-0.159***
				[0.009]				[0.006]
Spline 8^{th} decile control				-0.197***				-0.224***
				[0.013]				[0.013]
Spline 9^{th} decile control				-0.013				-0.003
				[0.022]				[0.022]
Spline 10^{th} decile control				-0.237***				-0.236***
				[0.013]				[0.013]
Observations	6 016 788	6 016 788	6 016 788	6 016 788	6 016 788	6 016 788	6 016 788	6 016 788
Adjusted R^2	0.255	0.065	0.078	0.069	0.250	0.093	0.105	0.089
Wu-Hausman test statistic	248 526***	371 822***	400 518***	363 206***	173 501***	282 371***	304 399***	289 339***
Robust F-statistic	8519***	40 039***	40 419***	16 244***	6767***	37 509***	32 233***	11 944***

Estimates of 2SLS regressions. *, **, *** reflect significance at the 5%, 1% and 0.1% levels, respectively. Regressions weighted by income. All regressions include dummy variables for each base year.

$\log[(1 - T_2')/(1 - T_1')]$. This, combined with the first stage results reported in Appendix A, suggests that the instrumental variables approach is appropriate.

In the basic results recorded in Table 2.4, models 1 and 5 are likely misspecified given that they do not control for mean reversion, which produces elasticity estimates outside of the plausible range. Models 2 to 4 suggest that there is a sizeable response of taxable income to tax changes when controlling for mean reversion and the widening of the income distribution - estimated elasticities range between 0.26 and 0.31. This is well within the span of the post-Feldstein literature.[30] In contrast, the elasticity of broad income is much smaller (models 6 to 8). The

[30] As an additional sensitivity analysis, Gruber and Saez (2002) are followed and the change in log income is censored at five so that the approximately 3000 observations who report changes in income ratios across the two years of more than 150 or less than 1/150 are censored. This avoids the influence of job shifting (to some extent) and/or large once-off increases/decreases in income. The results are not very sensitive to this restriction (see the Appendix for more details) and as such the paper proceeds with the uncensored dataset.

gap can partly be explained by changes in itemisation and/or exemption behaviour.

It must be noted that the estimated elasticities reported in Table 2.4 likely underestimate the full behavioural response to a change in the marginal tax rate. While the 'bracket creep' phenomenon studied here provides for some variation in marginal rates over the sample period and allows for the use of a difference-in-differences estimator, the implicit tax changes were relatively small and unlegislated. The absence of any legislated and well-publicised tax reform over the sample period implies that the behavioural response to changing tax rates might not be fully captured in the current framework. On the other hand, the particular economic circumstances of the period in question might have *increased* taxpayer sensitivity to changing tax rates. The sharp decline in economic activity in 2009, and subsequent recovery, likely induced behavioural responses on the part of the taxpayer in an attempt to stabilise disposable income in the face of 'bracket creep'. Additionally, research has shown that failure to account for excess mass at parts of the distribution (i.e. bunching at kink points) might produce biased, and often larger, elasticity estimates (see Chetty et al. (2011) and Gelber et al. (2013) for examples).

Finally, the data precludes the identification of the source of the behavioural response. As mentioned above, the ETI aims to capture all possible behavioural responses to changes in income taxation, including labour supply choices and tax evasion/avoidance, in a single measure. The source of the behavioural response is of obvious importance for the formulation of policy. Unfortunately, evidence on labour supply elasticities with respect to changing tax rates, and/or tax evasion and avoidance, for the South African economy, is scant.

There is some limited evidence on the responsiveness of labour supply to real wages. However, in general, there is little focus on the influence of wage growth (in particular) on labour supply in the South African context, with most authors focusing on the demographic drivers of labour force participation instead. The evidence that is available is mixed. Von Fintel (2017) used a district pseudo-panel, constructed from household surveys, to estimate the elasticity of labour demand, labour supply, and unemployment with respect to wages and found that labour supply is generally inelastic with respect to wages. Fedderke (2012) surveyed the evidence on labour market rigidities and found that some studies imply (relatively) high labour supply elasticities, while others point to lower values. One problem is that there is little consensus on the correct way to estimate these elasticities. Be that as it may, the literature does suggest that elasticities are generally non-zero, suggesting some supply response to changing wages. If one considers the fact that migrating to a higher tax bracket can result in lower take-home pay (i.e. lower real income), at least some of the behavioural response to changing tax rates can be assumed to originate from a labour supply response.

Turning to tax evasion/avoidance, the evidence is spread thin. Most studies comprise surveys among different population groups with respect to their attitude toward tax avoidance strategies. For example, Oberholzer and Stack (2014) found that different population groups have different opinions on tax evasion/avoidance, but that, in general, 25% of respondents express the desire to keep all earned income (i.e. not pay taxes), while 13% believe many other people avoid paying taxes and so see nothing wrong with doing the same. Robinson and Gcabo (2007) found that 50% of respondents in their survey would consider cheating on their taxes under certain circumstances. Ross and McGee (2012) found that attitudes toward tax evasion differ by demographic variable, with higher income individuals being more amenable to tax avoidance strategies. The results on the acceptability of tax avoidance suggest that at least some of the behavioural response captured in the estimated ETI can be attributed to tax evasion/avoidance. However, the dataset precludes the estimation of the magnitude of the response.

2.3.5 Sensitivity Analysis

Gruber and Saez (2002) were followed in performing sensitivity analysis along two important dimensions.

Variations in Timing

Previous literature was followed in using a three-year difference in computing both the change in taxable income and the change in after-tax shares. Using the framework above, the sensitivity of the results to a change in the difference window can be tested.

As noted in Saez (2003), the exact implications of changing the window of observation is not clear. A longer window might lead to higher elasticity estimates in the case where individuals react slowly to tax changes. However, if responses to tax changes happen largely through the timing of income reporting, then a longer difference window might produce lower elasticity estimates. In the case of unlegislated tax changes, such as the 'bracket creep' phenomenon investigated here, a longer window would more than likely lead to higher estimated elasticities. Over time, individual taxpayers should become more aware of the implications of 'bracket creep' and adjust their behaviour accordingly.

These issues are explored in Table 2.5.[31]

Table 2.5: Variations in timing

	3-year lag	2-year lag	1-year lag
Broad income	0.139	0.061	-0.024
	[0.018]	[0.015]	[0.013]
Taxable income	0.262	0.186	0.107
	[0.019]	[0.015]	[0.014]
Observations	6 016 788	9 025 182	12 033 576

Estimates of 2SLS regressions. Regressions weighted by income. All regressions include log income, polynomials in base year income, and dummy variables for each base year.

The window is first narrowed to two years and then to one year. As is clear from the table, estimated elasticities are considerably smaller (and in one case of the wrong sign) when using a one-year window versus a three-year window. This is consistent with the expectation that unlegislated (and relatively small) tax changes will not be immediately apparent to individual taxpayers and might take time to affect actual behaviour. Since the long-run response is of most interest, and since this is the focus of previous work, a 3-year window is used in the rest of the paper.

Heterogeneity

A salient feature of the South African tax system, and indeed any progressive tax system, is that taxes are not linear and do not apply equally to the entire universe of taxpayers. Effective tax rates differ both across income groups and between groups, with itemisers and non-itemisers, for example, facing different effective tax rates. In accordance with the international literature, it has already been seen that the behavioural response to a change in tax rates is much larger

[31] Table 2.5 and all subsequent tables use the preferred specification, which includes log income and polynomial terms in base year income as controls, and base year and itemiser dummies.

for itemisers relative to non-itemisers. Therefore, heterogeneity across income groups will be considered next.

The literature review highlighted the fact that estimated elasticities are, generally speaking, substantially higher for high-income earners than for those at the bottom of the income distribution. This is due to the fact that a larger share of their income comes in forms that are more easily manipulable for tax purposes (Gruber and Saez, 2002). For example, for higher income households, capital and investment income will feature more prominently. These sources of income are easily manipulable through, for example, asset allocation decisions. In contrast, for lower income groups the largest share of income is labour income, which is withheld for tax purposes through the pay as you earn (PAYE) mechanism. Therefore, the only way for individuals in lower income groups to manipulate reported income is through labour supply decisions, i.e. deciding to work more or less.

Most papers in the international literature focus on one specific reform to identify the ETI. In these cases, most of the variation comes across income groups, making it difficult to identify within-group behavioural responses. In contrast, Gruber and Saez (2002) use several reforms over multiple decades. These reforms impacted different points in the income distribution at different times, making it possible to identify within-group effects.

This paper (and the paper by Saez (2003)) falls somewhere in between. In South Africa, and indeed in the US, 'bracket creep' affected different points in the income distribution in different ways and at different times because nominal tax brackets were not uniformly adjusted between tax years. For example, between 2008 and 2011, the bottom tax bracket was adjusted by a cumulative 30%. However, between 2009 and 2012, the cumulative adjustment was only 17%. At the top end of the distribution, the cumulative adjustments were 18.5% and 17.5%, respectively. This generates *some* within-group variability which allows us to investigate group specific behavioural responses to changing tax rates.

However, as the within-group variation due to 'bracket creep' is rather limited, the estimates are not very precise. Additionally, the lack of significant within-group variation precludes the estimation of group-specific behavioural elasticities at a fully disaggregated level. As such, attention has been restricted to relatively broad income categories.

Table 2.6 gives the estimation results for these broad income categories. Columns (1) and (2) in Table 2.6 look at the bottom 50%, top 50%, and top 10% of income earners for broad and taxable income, respectively. Income cuts are based on base year income. Column (3) provides estimates based on income tax brackets, comparing individuals in the bottom two tax brackets (based on base year income) to those in the middle two and top two income tax brackets.

It is clear from the table that most of the action in terms of the behavioural response to changing tax rates is concentrated in the higher income groups, no matter the definition used. While estimates for lower income groups are small, statistically insignificant, and often of the wrong sign, the elasticity estimates for higher income groups are significantly larger. This is particularly true when looking at the top 10% of earners (for both broad and taxable income) and for individuals in the top two tax brackets (defined based on base year taxable income).

While the estimated elasticities for the highest income taxpayers are much larger than for lower income taxpayers, elasticities are imprecisely estimated with large standard errors. Given this imprecision, the patterns can only be taken as suggestive. Additionally, the estimated elasticities likely underestimate the response of taxpayers to changing tax rates. As mentioned above, Van Heerden (2013) estimated implied personal income tax elasticities using macro data and finds elasticities of between 0.38 and 0.79 for the various income groups under consideration. Despite these caveats, the estimates confirm the standard intuition that higher income taxpayers are more responsive to changes in marginal tax rates than lower income taxpayers.

Table 2.6: Elasticity estimates by income groupings

	Broad income (1)	Taxable income (2)	Taxable income (using taxable income cuts) (3)
Bottom 50% (bottom two tax brackets col. (3))	-0.118	0.0788	-0.0433
Standard deviation	[0.016]	[0.018]	[0.014]
Observations	3 008 400	3 008 387	4 113 977
Top 50% (middle two tax brackets col. (3))	0.103	0.111	-0.044
Standard deviation	[0.055]	[0.063]	[0.014]
Observations	3 008 388	3 008 401	1 287 080
Top 10% (top two tax brackets col. (3))	0.551	0.370	0.301
Standard deviation	[0.295]	[0.424]	[0.407]
Observations	601 680	601 678	615 731

Estimates of 2SLS regressions. Regressions weighted by income. All income ranges based on base year income.
All regressions include log income, polynomials in base year income, and dummy variables for each base year.

2.4 Optimal Taxation

This section draws on the empirical framework above to provide a computation of the optimal income tax system that is both theoretically sound and empirically based. The framework for the basic model is described in Saez (2001, 2004) and Saez et al. (2012), and summarised in Giertz (2009) and Diamond and Saez (2011).[32]

Recall that the literature on behavioural responses to taxation attempts to estimate the ETI as defined in equation (2.2.4), repeated here for convenience.

$$e = \frac{(1-\tau)}{z}\frac{\partial z}{\partial(1-\tau)}$$

As discussed in the previous section, a number of empirical studies, including this one, have found that higher income earners are much more responsive to changes in taxation than low income earners. As such, the analysis of optimal taxation will focus on higher income earners.

Following Saez et al. (2012), it can be assumed that individuals in the top bracket, who earn above a given reported income threshold $\bar{z}$, face a constant marginal tax rate τ.[33] The number of taxpayers in the top bracket is denoted by N. It is further assumed that the average level of reported income in the top bracket, z^m, depends only on the marginal net-of-tax rate, $(1-\tau)$. The aggregate elasticity of income in the top bracket with respect to the net-of-tax rate is then defined as $e = \frac{(1-\tau)}{z^m}\frac{\partial z^m}{\partial(1-\tau)}$. This aggregate elasticity is equal to the average individual elasticities weighted by individual income.[34] Most empirical studies weight individuals by their income so that they contribute to the aggregate elasticity in proportion to their incomes.

An increase in the marginal rate faced by those in the top bracket, τ, will have three distinct effects (Diamond and Saez, 2011; Kiss, 2013). The first is a mechanical effect (dM) and shows the increase in tax revenue due to the higher tax rate:

$$dM \equiv N[z^m - \bar{z}]d\tau > 0 \tag{2.4.1}$$

[32]For a more detailed discussion on optimal taxation theory, see Piketty and Saez (2012).

[33]For example, in the case of the 2008/09 tax year, individuals who earned above $\bar{z} = \text{R}490,001$ were taxed at the top marginal tax rate of $\tau = 40\%$.

[34]That is, $z^m = [z_1 + ... + z_N]/N$ and hence $e = [(1-\tau)/z^m]\partial z^m/\partial(1-\tau) = (1-\tau)[\partial z_1/\partial(1-\tau) + ...\partial z_N/\partial(1-\tau)]/Nz^m = [e_1 \cdot z_1 + ... + e_N \cdot z_N]/[z_1 + ... + z_N]$ where e_i is the elasticity of individual i.

Second, the increase in the tax rate induces a behavioural response that reduces the average reported income among high-income earners by $dz = -e \cdot z^m \cdot d\tau/(1-\tau)$. A change dz changes revenue by τdz. Therefore, the change in tax revenue due to the behavioural response (dB) is equal to:

$$dB \equiv -N \cdot e \cdot z^m \cdot \frac{\tau}{(1-\tau)} d\tau < 0 \tag{2.4.2}$$

These two effects combined will give the total revenue effect of any given change in the marginal tax rate τ and can be used to calculate the revenue maximising top marginal tax rate.

However, to calculate the *optimal* marginal tax rate for high income earners, the welfare loss associated with a higher tax burden needs to be taken into account. This is given by:

$$dW \equiv -g \cdot N[z^m - \bar{z}]d\tau < 0 \tag{2.4.3}$$

where g is the average marginal value of consumption for those earning more than $\bar{z}$.

By summing the three effects, the change in total welfare due to the increase in the marginal rate is obtained:

$$dT = dM + dW + dB = Nd\tau(z^m - \bar{z}) \cdot \left[1 - g - e \cdot \frac{z^m}{z^m - \bar{z}} \cdot \frac{\tau}{1-\tau}\right] \tag{2.4.4}$$

Equation (2.4.4) can be simplified and used to calculate the optimal marginal tax rate for those earning more than $\bar{z}$. The ratio $\frac{z^m}{z^m - \bar{z}}$ can be denoted by a, the so-called Pareto parameter. The parameter a measures the thinness of the top tail of the income distribution: the thicker the top tail of the income distribution, the larger is z^m relative to $\bar{z}$ and the smaller is a (this parameter will be returned to below). Using this definition of a, equation (2.4.4) can be written as:

$$dT = dM\left[1 - g - \frac{\tau}{1-\tau} \cdot e \cdot a\right] \tag{2.4.5}$$

At the optimal tax rate τ^*, $dT = 0$. This follows from the fact that, if a small tax increase (decrease) raises (reduces) total tax revenue, the fiscal authority would have an incentive to increase (decrease) the tax rate even further. Therefore, the initial tax rate could not have been optimal. Setting (2.4.5) equal to zero and rearranging, the following simple expression for the optimal rate τ^* is obtained:

$$\tau^* = \frac{1-g}{1-g+a \cdot e} \tag{2.4.6}$$

The parameter g is a function of society's preferences and as such it is difficult to pin down plausible values. By setting $g = 0$, one can obtain an upper bound to the top marginal tax rate. In this case, the value that society attaches to every additional rand retained by high income earners is negligible relative to an additional rand kept by the average earner.

Setting $g = 0$ in equation (2.4.6) gives the following expression for the top marginal tax rate:

$$\tau^* = \frac{1}{1+a \cdot e} \tag{2.4.7}$$

In this case, τ^* is equal to the revenue-maximising rate (Saez et al., 2012). It takes into account only the impact on total tax revenue of the mechanical (dM) and behavioural (dB) effects of a change in tax rates, ignoring the change in welfare experienced by those affected by the change.

Brewer et al. (2010) and Diamond and Saez (2011) argue that $g = 0$ is plausible for top earners (the top 1% in their definition). In fact, according to Kiss (2013), for most reasonable social welfare functions g is decreasing in income. Note that g does not have to converge to zero for the revenue-maximising rate to be approximately optimal. The parameter g enters (with the same sign) in both the denominator and numerator of (2.4.6) and therefore will have only second order effects as long as g is not too large. A sensitivity analysis with respect to the parameter g is performed below.

2.4.1 Revenue-maximising Constant Rate

Before discussing optimal tax results, it is worth considering a more straight-forward application of the estimated elasticities: the revenue maximising constant (or flat) tax rate.

Recall that $a = \frac{z^m}{z^m - \bar{z}}$ in equation (2.4.7). Note that $a = 1$ when a single flat tax rate applies to all incomes, i.e. $\bar{z} = 0$. In this case, the revenue-maximising rate (2.4.7) becomes the well-known expression $\tau^* = 1/(1+e)$. Using the results in Table 2.4 columns (4) and (8), a revenue-maximising rate equal to 79% for taxable income (elasticity of 0.262) and 87% for broad income (elasticity of 0.139) was obtained.

As mentioned before, the elasticity estimates presented here likely underestimates the behavioural response of taxpayers to changing tax rates. In fact, using an average (unweighted) elasticity of taxable income equal to 0.65, calculated as the average of the elasticity estimates for the different income groupings in Van Heerden (2013), the revenue-maximising constant rate for taxable income falls to 61%.

Given that $a \geq 1$, the flat revenue-maximising rate is always larger than the revenue-maximising rate for top income earners only. That is because increasing the top tax rate collects revenue only on those earning in excess of $\bar{z}$, but produces a behavioural response almost as large as an across-the-board increase in the marginal tax rate (Saez et al., 2012).

2.4.2 Optimal Tax Results

Most studies on optimal taxation focus on the top 1% of income earners, or at least those in the top income tax bracket. However, as mentioned in Section 2.3.3 and discussed in Section 2.3.5, the value for the chosen instrument is zero in the top income tax bracket. Given that the top 1% of income earners find themselves in the top income tax bracket, this lack of within-group variation precludes the estimation of a group-specific behavioural elasticity for those individuals at the very top of the income distribution.

In what follows, the results from Table 2.6 column (2) for the top 10% of income earners will be used to derive both the revenue-maximising and optimal marginal tax rate for those individuals at the top of the income distribution. As this grouping does not conform to an official category within the tax code, the derived optimal tax rates are purely illustrative, serving as an indication of the average optimal marginal tax rate applicable to the top two income tax brackets.[35]

First, the empirical value of the Pareto parameter a in equation (2.4.6) is estimated. Recall that parameter a is defined as $a = \frac{z^m}{z^m - \bar{z}}$, that is for income limit $\bar{z}$, a is equal to the average income of individuals above the limit divided by the difference of that average and the income limit. For a Pareto distribution, the quantity $\frac{z^m}{\bar{z}}$ is constant and equal to $\frac{a}{a-1}$. Distributions with a constant $\frac{z^m}{\bar{z}}$ are exactly Pareto distributions. The tails of empirical earnings distributions can be remarkably well approximated by Pareto distributions.

[35] Across all the years in the sample, the top two income tax brackets contained all of the top 10% of income earners.

Figure 2.2: Value of $\frac{z^m}{\bar{z}}$ as a function of the chosen income limit

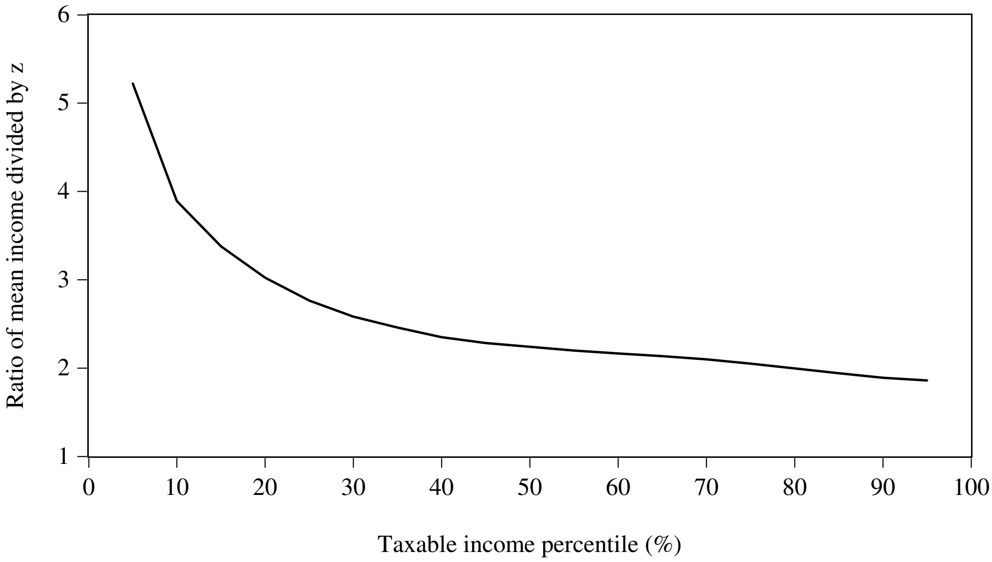


Figure 2.2 shows the value of $\frac{z^m}{\bar{z}} = \frac{a}{a-1}$ for the different percentiles of the taxable income distribution in our panel. The parameter declines notably between the 5^{th} and 90^{th} percentiles before stabilising at a value of just below 2, suggesting that the right tail of the income distribution is approximately Pareto distributed.

As mentioned before, the higher the parameter a, the 'thinner' the top end of the distribution. This implies that for a given value of g and e in (2.4.6), a higher value for a would result in a larger behavioural response to a change in tax rates, a larger excess burden of taxation and a lower optimal top tax rate (Steenekamp, 2012).

For the top 10% of income earners in our sample (based on real base year taxable income), $\bar{z}$ is equal to around R382 000 and z^m is equal to around R721 000, resulting in an estimate for a of 2.13. While the paper focuses on the top 10% of income earners, this estimate compares favourably to others in the literature. Using the same methodology and utilising data from the 2011 Tax Statistics publication, Steenekamp (2012) estimates a value for a of 2.11 for the top 1% of South African taxpayers. This compares with estimates for the top 1% of income earners of 2.5 for Hungary (Kiss, 2013), 1.8 for the UK (Brewer and Browne, 2009), 1.6 for New Zealand (New Zealand Treasury, 2009), and 1.5 for the US (Saez et al., 2012).

Revenue-maximising marginal rate

By setting $g = 0$, the revenue-maximising marginal rate for the top 10% of income earners can be derived using equation (2.4.6). Table 2.4 indicates that the ETI for the top 10% of income earners is 0.37. Plugging this into (2.4.6) and setting $g = 0$ and $a = 2.13$, the revenue-maximising rate for the top 10% of income earners is equal to 56%. Note that this is lower than the revenue-maximising constant rate applicable to the entire income distribution as calculated in Section 2.4.1.

Optimal marginal rate

To calculate the *optimal* marginal tax rate, the welfare loss associated with an increase in the marginal rate, i.e. g, has to be taken into account. A popular benchmark for calculating the value of g, also used by Diamond and Saez (2011), supposes that the average marginal value of consumption is inversely proportional to income. The paper follows Kiss (2013) in setting g equal to the inverse of the ratio of the average income of the respective income group to overall average income. For the top 10% of income earners in the sample this implies that $g = 0.28$, similar to the value estimated for Hungary in Kiss (2013).

Setting $g = 0.28$, $a = 2.13$ and $e = 0.37$ in (2.4.6), the optimal marginal tax rate for the top 10% of income earners in this sample is equal to 48%.[36]

At first glance, the calculated optimal rate seems to be at odds with the legislated marginal tax rates for top income earners: over the sample period in question, legislated marginal tax rates were set at 38% and 40% for the top two income tax brackets respectively. However, the actual tax rate that should be compared to this theoretical benchmark is not simply the legislated personal income tax rate. According to Kiss (2013), the tax rate corresponding to the theoretical benchmark should answer the following question: By how much can an individual increase their consumption if total labour cost is increased by one unit? Therefore, at a minimum, consumption taxes should also be taken into consideration.

The actual marginal rate that should be compared to the theoretical benchmark is then given by:

$$\tau = 1 - (1 - \tau_{cons}) \cdot (1 - \tau_{pit}) \tag{2.4.8}$$

where τ_{cons} is the effective consumption tax rate and τ_{pit} is the applicable marginal tax rate.

Kiss (2013) and Brewer et al. (2010) were followed in calculating the effective consumption tax rate as government revenue from domestic taxes on goods and services divided by total private consumption from National Accounts data. This results in an average effective consumption tax rate of 14.2% over the sample period in question, marginally higher than the legislated VAT rate of 14%.[37] It should be noted there are a list of goods that are zero-rated and/or exempt from VAT, including several basic foods items, illuminating paraffin, other fuel subject to the fuel levy, and certain goods and services. This reduces the regressive nature of VAT and justifies applying the same effective consumption tax rate across the income distribution in the calculation of the effective marginal rate.

Using (2.4.8), setting $\tau_{cons} = 14.2\%$ and τ_{pit} equal to 38% and 40%, it is seen that the corresponding actual effective marginal rates for the top two income tax brackets are 46.8% and 48.5%, respectively. This corresponds well to the VAT-inclusive effective marginal rate of 47.4% as calculated in Van Heerden (2013) and Steenekamp (2012) for the top income tax bracket. This implies that the actual effective marginal tax rates for the top two income tax brackets (which encapsulates the top 10% of income earners) in our sample is very close to the theoretically implied optimal level of 48%. Broadening the sample to include the 2013/14 to 2016/17 tax years and taking into account the increase in the legislated marginal tax rate for the top two income tax brackets to 39% and 41% in 2015, implies that the actual effective marginal rates are 47.9% and 49.7%, respectively, with the latter above the theoretically implied optimal. While tax and consumption data for 2017 are not yet available, it is safe to assume that the creation of a new top income tax bracket in the February 2017 Budget (with marginal rate of 45%) implies that the effective marginal tax rate for top income earners is likely in excess of 50%, substantially higher than the calculated optimal rate of 48%.

These calculations imply that the introduction of the new top marginal tax bracket might not yield the desired revenue results. This is confirmed by Jordaan and Schoeman (2015). The authors use a microsimulation model and suggests that the most favourable scenario for reaching the optimal PIT-to-GDP ratio would be to *lower* marginal rates. The corresponding

[36] It is important to note that, given the fact that the elasticity of 0.37 likely underestimates the behavioural response of taxpayers at the top end of the distribution to changing tax rates, the actual optimal marginal tax rate for top income earners might in fact be lower than 48%.

[37] See the Appendix for further information on the calculation of the effective consumption tax rate.

loss in revenue will have to be compensated for, but basic theory explains that, in the longer term, the revenue base will be broadened as a result of the efficiency gains that exceed the loss in revenue.

It is important to note that effective marginal rates calculated here still do not fully reflect the actual marginal rate faced by the taxpayer as several taxes are not included in the calculation (e.g. capital gains tax, dividends tax, taxes on fringe benefits, among others). However, by including consumption taxes one can arrive at a measure that is more closely related to the optimal tax rate in equation (2.4.6).

Sensitivity analysis

As mentioned in Section 2.3.5, the lack of significant within-group variation resulted in imprecise elasticity estimates for the top 10% of income earners. In order to test the sensitivity of the optimal tax rate calculation, Table 2.7 shows the calculated optimal marginal tax rate as a function of g and e with a fixed at a value of 2.13.

Table 2.7: Optimal marginal tax rates for the top 10% as a function of g and e

	Values of e				
Values of g	0.2	0.3	0.4	0.5	0.6
0.0	70%	61%	54%	48%	44%
0.1	68%	59%	51%	46%	41%
0.2	65%	56%	48%	43%	39%
0.3	62%	52%	45%	40%	35%
0.4	59%	48%	41%	36%	32%

Author's calculations.

Small changes in g have little effect on the optimal rate. To take an example, choosing $g = 0.1$ instead of $g = 0$ affects the optimal rate very little: for our central parameter estimates of $a = 2.13$ and $e \approx 0.4$ the optimal rate becomes 51% instead of 54%. The optimal rate is, however, substantially affected by the elasticity estimate e. The is particularly true at lower values for e: moving from $e = 0.2$ to $e = 0.3$ results in an average decrease in the optimal rate of around nine percentage points, depending on the value of g. This moderates to a decline of around four percentage points when moving from $e = 0.5$ to $e = 0.6$.

Our central parameter estimates ($g = 0.28$, $e = 0.37$ and $a = 2.13$) implies that the optimal marginal tax rate for the top 10% of income earners is around 48% (consistent with a legislated marginal PIT rate of around 40%). However, as mentioned throughout the text, elasticity estimates based on the 'bracket creep' phenomenon likely underestimates the behavioural response of high-income earners to tax changes (see also Van Heerden (2013) for alternative elasticity estimates). Therefore, given the estimates for g and a, the optimal marginal tax rate for higher-income earners might be closer to 40%, or even below.

2.5 Conclusion

The magnitude of the behavioural response of taxpayers to changing tax rates is of critical importance in the formulation of tax and transfer policy, as well as for the study of the welfare implications of tax decisions.

In the absence of any large tax reforms over the sample period in question, the phenomenon of 'bracket creep' was used to estimate the elasticity of taxable income with respect to changing tax rates in South Africa. The elasticity for taxable income is estimated at around 0.3, while that for broad income is estimated at closer to 0.2. These estimates lie close to the mid-point of the post-Feldstein literature. Additionally, it was found that behavioural responses are concentrated in higher-income groups as suggested by the higher elasticity estimate (0.37 for taxable income) for the top 10% of income earners.

Using these elasticity estimates as an input in an optimal taxation framework, it was found that the optimal tax rate for the top 10% of income earners is in line with a legislated marginal PIT tax rate of around 40%. Significant increases in the legislated marginal tax rate could trigger behavioural responses that would nullify any potential revenue gain. This result is particularly important given the recent introduction of a new top income tax bracket with legislated marginal tax rate of 45%. In light of the calculations presented in this paper, the introduction of this new tax bracket might not yield the desired revenue results.

While the use of 'bracket creep' to identify the ETI is useful in the case where large tax reforms are unavailable, several caveats do apply. First, precisely because 'bracket creep' is not a legislated tax change, taxpayers may not be fully aware of the implications for after-tax income and thus might not respond meaningfully to the associated increase in marginal rates. This implies that one should think carefully before using the estimates in this chapter to predict the effects of future (legislated) tax reforms. That being said, by using a three-period difference in the estimation exercise, this shortcoming might be mitigated somewhat as taxpayers become more aware of the cumulative impact of 'bracket creep' on their tax liability over time and respond accordingly.

Second, the anatomy of the behavioural response was not investigated. It would be very useful to investigate how different income sources respond to changing tax rates. This would provide insight into which income sources explain the behavioural response observed at the level of total taxable income. This is arguably more important when it comes to the formulation of tax policy.

Third, the heterogeneous elasticity estimates are imprecisely measured and, as such, the optimal tax results should be seen as purely suggestive.

Despite these caveats, the analysis presented in this chapter represents the first of its kind in South Africa and provides a solid starting point for further investigation into the behavioural response of taxpayers to changing tax rates.

Chapter 3

Empirical estimates of fiscal multipliers for South Africa

3.1 Introduction

Measuring the impact of fiscal policy decisions on aggregate gross domestic product (GDP) and its components was an active research area for a number of decades during the mid-20th century. The large Keynesian models of the 1960s included fiscal variables and numerous empirical papers investigated their effects on macroeconomic variables through the estimation of behavioural equations (Ramey, 2016). However, from the 1980s to early-2000s, most empirical research on shocks focused on monetary policy. With the onset of 2008/09 Global Financial Crisis (GFC) and the emergence of the zero lower bound, attention shifted to the effects of fiscal policy.

Despite the strong policy response from monetary authorities during and immediately after the GFC, it soon became apparent that the standard monetary policy toolkit was insufficient to offset the dramatic fall in economic activity. While standard interest rate tools were used to aggressively loosen monetary policy in the wake of the GFC, central banks also implemented what could be referred to as "quasi-fiscal policy". Quasi fiscal policy refers to policies that, instead of being innate to central banks, could have been implemented by fiscal authorities (Park, 2015).

Given the apparent inability of both standard and unconventional monetary policy tools to stimulate global demand, there was renewed debate on the role of discretionary fiscal policy in stabilising the global economy. In the decades prior to the crisis, the consensus was one predicated on the idea of fiscal discipline. Fiscal stabilisation was, broadly speaking, relegated to automatic stabilizers rather than discretionary fiscal policy. However, in the wake of the GFC, governments, as well as institutions generally viewed as sympathetic towards fiscal austerity (such as the International Monetary Fund or the European Commission), advocated for large fiscal stimulus programmes.

While some have argued that fiscal activism had actually been practised quite some time prior to the crisis (see, for example, Auerbach (2009) for the US and Cecchetti et al. (2010) for several OECD countries), it was only after the crisis that activist policy was formally back on the agenda. Across the globe, fiscal policy was employed in concert with the fall in interest rates and the expansion of central bank balance sheets in an attempt to bolster economic growth.

Despite the frequent use of fiscal policy for stabilisation purposes and the important role fiscal activism played in the wake of the GFC, the size of budgetary multipliers, which measures the output response following an *exogenous* shock to fiscal policy, has been heatedly debated at both the theoretical and empirical level. In fact, in the empirical literature, which is largely based on structural vector autoregressions (SVARs), there is little agreement on the size, and even the sign, of fiscal multipliers.[38] Caldara and Kamps (2008), Chahrour et al. (2012), Ramey (2016), and Caldara and Kamps (2017), among others, show that the wide range of fiscal multiplier estimates found in the literature is mainly due to differences in the approaches used to identify the underlying (structural) fiscal shocks.

This general results is also true in the context of South Africa. The few studies that have attempted to estimates fiscal multipliers for South Africa provide for a relatively wide range of estimates with results dependent on model specification and identification strategy. The same is true for the current study. Given the inherent ambiguity of multiplier estimates and important role that model specification/identification plays in the final results, caution should be applied when relying on these estimates to draw concrete policy conclusions.

Keeping in mid this important caveat, this chapter estimates fiscal multipliers for South Africa using a variety of identification approaches and model specifications. The main findings show that the size of budgetary multipliers is indeed sensitive to identification strategy and modelling approach. Despite this caveat, in general the estimation results show that government spending multipliers are positive, albeit generally smaller than one. In contrast, tax multipliers are large and distortionary. It is also shown that both spending and tax multipliers are larger when the economy is in a recessionary state (or downswing).

The rest of the chapter proceeds as follows: Section 3.2 provides some theoretical and empirical background, including a brief overview of the literature on budgetary multipliers. Section 3.3 discusses the baseline empirical strategy, while Section 3.4 provides baseline fiscal multiplier estimates. Section 3.5 investigates alternative model specifications. Section 3.6 estimates state-dependent fiscal multipliers for South Africa, while 3.7 presents some caveats and concluding comments.

3.2 Theoretical and empirical background

3.2.1 Theoretical predictions

While the identification and estimation of the effects of fiscal policy changes on macroeconomic outcomes (i.e. fiscal multipliers) appear at first glance to be a purely empirical matter, economic theory tells us that there is no one single government spending or tax multiplier. In fact, the effect of fiscal policy shocks on broader macroeconomic outcomes depends potentially on a range of factors. These include the persistence in the change in fiscal variable, the type of public spending and/or taxes that changed (e.g. consumption versus investment spending, personal versus corporate taxes), how the change was financed (e.g. deficit/debt-financed or balanced-budget), how the change was distributed across economic agents, the response of monetary policy, the state of the economy at the time of the change, and various other features of the economy such as the level of development, exchange rate regime, openness (Ramey, 2019)

There are three broad theoretical frameworks that provide an underpinning for the effects of fiscal policy on macroeconomic outcomes. The Keynesian model, which assumes that the level of GDP is demand-determined over the short-term, treats the government spending multiplier as the inverse of one minus the marginal propensity to consume (Ramey, 2019). In this model, taxes enter the multiplier only through their effect on disposable income and, as such, tax multipliers are smaller (and of the opposite sign) than spending multipliers. Expanding these models to incorporate features such as the marginal propensity to import (i.e. 'opening up' the model economy), tax rates, and monetary policy leads to smaller spending multipliers.

[38]See Ramey (2016) for a review of the relevant literature.

Neoclassical models, which include variable labour supply and variable capital stock, also predict positive spending multipliers and negative tax multipliers. However, the transmission mechanism is different from the one in the Keynesian model. In the neoclassical model, a positive government spending shock generates a negative household wealth effect. This negative wealth effect induces households to work more (i.e. the shock induces a positive labour supply response), thereby raising GDP. Distortionary taxes have potentially large negative effects in these models. However, in contrast to the simple Keynesian models where tax shocks work through aggregate demand, in the neoclassical framework, tax shocks affect economic outcomes through supply-side channels (Ramey, 2019).

Finally, New Keynesian models, embodied in New Keynesian Dynamic Stochastic General Equilibrium (NK-DSGE) models, combine elements of both Keynesian and neoclassical models. Standard representative agent sticky-price NK-DSGE models tend to produce small, albeit positive, government spending multipliers. In the last decade, the standard NK-DSGE model has been expanded to include, among other features, sticky wages, heterogeneous agents, and financial market frictions. In these models, agents tend to have much higher marginal propensities to consume, which can lead to larger spending multipliers. Following the GFC, a new generation of NK-DSGE models have explored the effects of fiscal policy under unconventional monetary policy arrangements, particularly in cases where policy rates are constrained by the zero lower bound. These extensions often result in large spending multipliers, in many cases larger than unity (Ramey, 2019).

When estimating the impact of fiscal policy changes on macroeconomic outcomes, it is important to keep these theoretical considerations in mind. It is important to be aware of which theoretical model is being used, while also being mindful of other factors that could influence the size and/or sign of fiscal multipliers. These include the particular institutional arrangements of the economy under investigation, how the change in fiscal policy is financed, the persistence of the fiscal shock or change in the particular fiscal variable, the exchange rate regime, the openness of the economy, and so forth.

Keeping these caveats in mind, the following sections briefly discuss the empirical literature on fiscal multipliers, starting with a brief overview of the main identification methods.

3.2.2 Identification of fiscal shocks

The empirical literature on fiscal multipliers is primarily concerned with estimating the effects of exogenous and/or unanticipated changes in fiscal variables on macroeconomic aggregates such as GDP and/or private consumption. In principle, a fiscal policy shock is a relatively straightforward concept. Fiscal authorities often make policy decisions based on considerations that are unrelated to the current state of the economy. For example, unanticipated changes in tax policy/regime might stem from a change in political power and/or equity concerns, while unanticipated spending shocks might stem from exogenous factors such as the outbreak of war. In contrast, the idea of regularly occurring exogenous shocks to monetary policy is less plausible given the fact that monetary policy decisions are highly dependent on the current state of the business cycle.

That being said, identifying exogenous (or structural) fiscal policy shocks in an empirical time series framework is far from straightforward. This section briefly discusses the problem of identifying fiscal shocks empirically, while also detailing some of the leading identification methods employed in the literature.

Ramey (2016) provides a simple framework for discussing the problem of identification. Consider a simple model of the relationship between fiscal variables and GDP. Suppose the structural relationships between government spending (g), taxes (τ) and GDP (y) is given by:

$$
\begin{aligned}
y_t &= \beta_{y\tau}\tau_t + \beta_{yg}g_t + \varepsilon_{yt} \\
g_t &= \beta_{g\tau}\tau_t + \beta_{gy}y_t + \varepsilon_{gt} \\
\tau_t &= \beta_{\tau g}g_t + \beta_{\tau y}y_t + \varepsilon_{\tau t}
\end{aligned} \tag{3.2.1}
$$

The ε's are the structural macroeconomic shocks of interest: $\varepsilon_{\tau t}$ is the tax shock, ε_{gt} captures an exogenous shock to government spending, and ε_{yt} captures business cycle shocks such as technological progress.

This simple model can be used to illustrate the main identification problem. Based on theoretical predictions, government spending might be expected to raise GDP (i.e. $\beta_{yg} > 0$) and an increase in taxes might be expected to lower it ($\beta_{y\tau} < 0$). However, the presence of automatic stabilisers imply that the fiscal variables might also respond to developments in GDP (i.e. $\beta_{gy} < 0$ and $\beta_{\tau y} > 0$). As a result, a simple OLS regression will lead to biased estimates of the parameters of interest ($\beta_{y\tau}$ and β_{yg}) because g_t and τ_t are correlated with ε_{yt}. Without further assumptions, neither the parameters nor the structural shocks are identified (Ramey, 2016).

This simple model can be expanded to a dynamic setting.[39] Consider the same model as above with three endogenous variables, Y_1, Y_2, and Y_3. In the context of fiscal policy, these might be GDP, government spending or investment, and tax revenue or marginal tax rates. Suppose that the dynamic behaviour of the vector of endogenous variables, $Y_t = [Y_{1t}, Y_{2t}, Y_{3t}]$, is given by:

$$
Y_t = B(L)Y_t + \Omega\varepsilon_t \tag{3.2.2}
$$

where $B(L) = B_0 + \sum_{k=1}^{p} B_k L^k$. The elements of B_0 are the same as the β's from equation (3.2.1) with $\beta_{jj} = 0$. As has become standard practice in the SVAR literature, the dynamics of the system can be investigated by rewriting (3.2.2) in its reduced form representation:

$$
A(L)Y_t = \eta_t \tag{3.2.3}
$$

where $A(L) = I - \sum_{k=1}^{p} A_k L^k$, and $\eta_t = [\eta_{1t}, \eta_{2t}, \eta_{3t}]$ is the reduced form VAR innovations. The reduced form innovations can then be linked to the (unobserved) structural shocks, ε, as follows:

$$
\eta_t = B_0\eta_t + \Omega\varepsilon_t \tag{3.2.4}
$$

or

$$
\eta_t = H\varepsilon_t \tag{3.2.5}
$$

where $H = [I - B_0]^{-1}\Omega$. If one assumes that Ω is an identity matrix and that the structural shocks, ε_t, have unit effects, the system can be written as:[40]

$$
\begin{aligned}
\eta_{1t} &= \beta_{12}\eta_{2t} + \beta_{13}\eta_{3t} + \varepsilon_{1t} \\
\eta_{2t} &= \beta_{21}\eta_{1t} + \beta_{23}\eta_{3t} + \varepsilon_{2t} \\
\eta_{3t} &= \beta_{31}\eta_{1t} + \beta_{32}\eta_{2t} + \varepsilon_{3t}
\end{aligned} \tag{3.2.6}
$$

This set of equations is the dynamic equivalent of equation (3.2.1). The only difference is that the structural relationships are written in terms of the reduced form VAR innovations, $\eta_{.t}$, as

[39] Stock and Watson (2016) provide a more detailed treatment of identification issues in a dynamic setting.

[40] These two simplifying assumptions are widely used in the SVAR literature. The first implies that each structural shock enters only one equation, while the second implies that the diagonal elements of H are unity.

opposed to the endogenous variables themselves. The interpretation of the coefficients remains the same. As discussed above, these coefficients, and the associated structural shocks, cannot be identified without additional restrictions.

The above discussion at the hands a relatively simple model highlights the fact that the identification of fiscal shocks is far from straightforward. Several of the leading approaches used to deal with the identification issue are discussed below.[41]

Cholesky decomposition

The most common identification scheme is based on the Cholesky (or recursive) decomposition, first introduced by Sims (1980). The most common variant of this identification method assumes that the policy variable does not respond contemporaneously (within the month, quarter or year) to the other endogenous variables in the system.

Suppose that, in the simple model discussed above, Y_1 is the policy variable (e.g. government consumption spending). The recursive identification scheme involves setting $\beta_{12} = \beta_{13} = 0$ in equation (3.2.6). This is equivalent to ordering the policy variable first in a VAR set-up. Alternatively, one could assume that the other endogenous variables do not respond contemporaneously to the policy shock, i.e. $\beta_{21} = \beta_{31} = 0$ in equation (3.2.6).

Other coefficient restrictions

Another approach, first introduced by Blanchard and Watson (1986) and Bernanke (1986), nests the Cholesky decomposition and is known as a *structural* VAR, or SVAR. This approach uses outside estimates and/or economic theory to constrain the contemporaneous responses of the endogenous variables. In a seminal paper by Blanchard and Perotti (2002), they use this approach to identify both government spending and net tax shocks. With reference to the simple framework discussed above, assume that Y_1 is government spending, Y_2 is net taxes and Y_3 is real GDP. The authors proceed to identify the government spending shock by using a recursive decomposition with government spending ordered first in the Cholesky ordering (i.e. $\beta_{12} = \beta_{13} = 0$). In contrast, net tax shocks are identified by using an outside estimate of the elasticity of tax revenue to GDP to constrain β_{23} in (3.2.6).

A second related approach uses long-run restrictions to identify policy shocks as opposed to constraining contemporaneous coefficients/responses. The most common form of long-run restriction is the infinite horizon restriction, introduced by Shapiro and Watson (1988) and popularised by Blanchard and Quah (1989). Instead of imposing zero contemporaneous restrictions on the system, the approach assumes that the policy variable(s) does not affect other endogenous variables (or set of endogenous variables) in the long run. In the simple framework discussed above, this is achieved by re-casting equation (3.2.2) in its moving average representation, $Y_t = C(L)\eta_t$ and combing it with equation (3.2.5) to express the Y's as a function of the structural shocks:

$$Y_t = D(L)\varepsilon_t \tag{3.2.7}$$

where $D(L) = C(L)H$. By placing restrictions on the elements of D, the structural shocks can be identified.

[41] See Ramey (2016) for further details.

Narrative methods

Narrative methods involve constructing a series of shocks based on historical documents and/or information reflecting the reason for and/or quantities associated with a particular change in the policy variable of interest (Ramey, 2016). These series are then used as exogenous inputs in a standard regression framework. Early examples of the use of narrative methods to identify policy shocks include Friedman and Schwartz (1963), Hamilton (1985), and Hoover and Perez (1994). Examples of the use of narrative methods to identify *fiscal* policy shocks include Poterba (1986), Ramey and Shapiro (1998), Romer and Romer (2010), and Ramey (2011b).

External instruments/Proxy SVARs

The external instrument or proxy SVAR method is a relatively new method for incorporating external information to aid in the identification of fiscal policy shocks. The method was developed by Stock and Watson (2008) and was extended by Stock and Watson (2012) and Mertens and Ravn (2013). The approach uses information external to the VAR, such as the narrative series discussed above, and uses it to identify the policy shock in question (see Ramey (2016) for more details). The approach has been extended to incorporate non-fiscal series as possible instruments to aid in the identification of fiscal shocks (see Caldara and Kamps (2017) for an example).

Sign restrictions

Several researchers have noted the circularity in the analysis of VAR specifications in practice. A particular specification and/or identification method is often deemed acceptable only if the impulse responses they produce are judged to be reasonable, i.e. consistent with the researchers' priors (Ramey, 2016). Faust (1998) and Uhlig (2005) developed the sign-restriction approach which incorporated reasonableness without undercutting the scientific process. The authors identified structural shocks to a particular variable Y by placing restrictions on the impulse responses of the other endogenous variables in the system (see Section 3.3.2 for details on the implementation of the approach). The sign restriction approach was initially used in the identification of monetary policy shocks, but has since been applied to the identification of other types of shocks, including total factor productivity (or technology) shocks and fiscal policy shocks.

Estimated structural models

A different approach to the identification of fiscal policy shocks relate to estimated dynamic stochastic general equilibrium (DSGE) models, introduced by Smets and Wouters (2003, 2007) and extended by numerous authors since. These models identify structural shocks by imposing a theoretically motivated structure on the model economy. The approach involves estimating a fully specified structural, general equilibrium model and extracting the set of implied structural shocks from those estimates. A variation on the standard procedure involves first estimating impulse responses in a standard SVAR set-up and then calibrating the parameters in DSGE model to match these responses (see Christiano et al. (2005) for an example of this approach).

The problem of nonfundamentalness

In a SVAR, linear combinations of structural shocks are estimated as residuals of an unrestricted VAR and the structural shocks are then identified by rotating the VAR innovations in a suitable way, i.e. by imposing restrictions. However, if the *structural* model has an moving average (MA) component, the VAR representation is admissible only under some conditions which may not be verified in the structural model. In particular, the VAR representation is admissible only if no root of the determinant of the matrix of the MA is inside the unit circle. If at least one root is smaller than one in modulus, there is a problem of nonfundamentalness of the structural shocks: VAR estimation will not recover them because of the need to invert the MA (Alessi et al., 2008). This is a consequence of the fact that the agents' information set is bigger that the econometrician's one. In the context of the identification of fiscal policy shocks, Leeper et al. (2013) show that failure to account for fiscal foresight (i.e. the broader information set of economic agents) in the estimation set-up could lead to nonfundamentalness and biased estimates for tax multipliers.

One way to deal with the problem of nonfundamentalness to enlarge the econometrician's information set. While it is not possible to include future observations, the cross-sectional dimension could be increased. To handle the ensuing problem of dimensionality, one might assume a factor structure in the data. Indeed, as shown in Alessi et al. (2008), dynamic factor models are able to retrieve the structural shocks even when a SVAR, because of nonfundamentalness, can not. A second alternative is to estimate the nonfundamental representations associated with the VAR, but this approach comes with its own set of difficulties.

3.2.3 Empirical literature

This section gives a brief overview of the empirical literature, with reference to the different identification approaches discussed above. Most of the literature has focused on the United States, while a limited number of studies have focused on other regions. [42]

Government spending shocks

Since the seminal work by Sims (1980), VAR models have become one of the primary tools to study macroeconomic dynamics. One of the first examples of a VAR-type analysis of the effects of fiscal shocks on macroeconomic outcomes is Rotemberg and Woodford (1992). The authors analyse the effects of changes in military spending and employment on macroeconomic variables in the United States. The method consisted of estimating three-variable VAR-type models with military spending, military employment, and the macroeconomic variable of interest as endogenous variables. Building on the work by Hall (1980, 1986) and Barro (1981), the authors achieved identification by arguing that significant changes in defence spending is not driven by macroeconomic developments, but rather by military events, thereby providing an exogenous shock to government spending.

Subsequent research expanded on the idea of using military events to identify the effects of unanticipated shocks to government spending. The seminal contribution by Ramey and Shapiro (1998) used the narrative method to create a dummy variable related to major military build-ups. The authors used news reports to identify political events that led to large military build-ups and construct a series that is orthogonal to the business cycle. Several follow-up papers, including Edelberg et al. (1999) and Burnside et al. (2004), embedded these 'war dates' in VARs, with the narrative series ordered first in a Cholesky decomposition, creating so-called expectations augmented VARs (or EVARs).[43] EVARs have been expanded to include other measures of expectations, such as forecast errors of professional and/or public sector forecasters, in order to account for the predictable and/or anticipated element of government spending; examples

[42]See Ramey (2016) and Ramey (2019) for detailed literature overviews.
[43]The term EVAR was coined by Perotti (2011).

include Auerbach and Gorodnichenko (2012b) and Alichi et al. (2019), among others. Most of these narrative-based studies found that shocks to government spending (as proxied by changes in military spending) led to increases in GDP and hours worked, at least in the short run, but that it lowered private consumption and investment.

This stands in marked contrast to results from the broader SVAR literature. In their seminal contribution, Blanchard and Perotti (2002) used an SVAR to identify both government spending and net tax shocks. In contrast to the military news identification scheme, they found that shocks to government spending raised not only real GDP, but also induced positive responses from private consumption, hours worked, and real wages. Subsequent studies in this tradition found similar results (see Fatás and Mihov, 2001; Perotti, 2005; Galí et al., 2007; Caldara and Kamps, 2008; and Pappa (2009), among others). In contrast, using the sign restrictions approach, Mountford and Uhlig (2009) found only weak expansionary effects of government spending on real GDP and no significant effect on consumption.

In an attempt to reconcile the apparent contradicting results from the narrative and SVAR approaches, Ramey (2011b) argued that changes in government spending are more often than not anticipated at least several quarters in advance. This implies that the SVAR method does not identify unanticipated shocks to government spending. In order to capture the 'news', or unanticipated, part of government spending shocks, Ramey (2011b) created a quantitative series of estimates of changes in the expected present value of government purchases caused by military events. Embedding this news series in an VAR framework, with the news variable ordered first in a standard Cholesky decomposition, the author found results that were broadly similar to those obtained from the simple war date series.

Ramey's (2011b) results emphasised the importance of foresight and highlighted the difficulty in identifying *unanticipated* shocks to government spending and/or taxes. Follow-up work created richer narrative measures in an attempt to control for anticipation effects. Important contributions include Fisher and Peters (2010), Owyang et al. (2013), Zeev and Pappa (2017), and Ramey and Zubairy (2018). One caveat is that since all these measures of anticipation are constructed with reference to military events, there are likely confounding effects which might contaminate the results (examples include rationing, price controls, and what Ramey (2016) calls "patriotic increases in labour supply").

Proxy VARs have become popular following the seminal work by Stock and Watson (2008, 2012), with several different instruments employed as proxies for spending shocks. Notable recent examples include Mertens and Ravn (2013), Caldara and Kamps (2017), and Arias et al. (2018). These papers found persistent and often large effects of government spending on output.

As mentioned above, a more structural and theoretically sound method for identifying exogenous government spending shocks is through estimated DSGE models. Notable contributions in this tradition include Forni et al. (2009), Cogan et al. (2010), Christoffel et al. (2011), Leeper et al. (2012), Coenen et al. (2013), and Leeper et al. (2017).

Broadly speaking, the literature focuses on two key aspects of government spending multipliers. As expected, a significant share of the literature is devoted to estimating the size of the spending multiplier. Not wholly unrelated to this, many studies also attempt to reconcile the apparent contradiction in results from the empirical literature relative to theoretical predictions of the effects government spending shocks.

Most standard theoretical models predict that an increase in government spending should raise GDP and hours worked but decrease private consumption and real wages. It is only through the inclusion of other elements in the model set-up, such as rule-of-thumb consumers, that one can generate positive responses in private consumption and real wages (see for example Galí et al. (2007)). In contrast, SVARS in the Blanchard and Perotti (2002) tradition typically predict an increase in private consumption and real wages following shocks to government spending, while

EVARs (and SVARS that include news shocks) typically produce qualitatively similar results to those of estimated DSGE models. This divergence once again highlights the importance of controlling for expectations in the model set-up.

Apart from attempting to match empirical results with theoretical predictions, the literature is also concerned with estimating the size of government spending multipliers. In a survey of the literature, Ramey (2016) found that most estimates of the government spending multiplier in the developed world vary between 0.6 and 1.5. Much less evidence is available for the developing world, but the scarce empirical literature suggests that multipliers are smaller in emerging- and low-income economies (see for example IMF, 2008; Ilzetzki, 2011; Kraay, 2012; Estevão and Samaké, 2013; Ilzetzki et al., 2013; Gnip, 2014; Batini et al., 2014; Alichi et al., 2019). Empirical research into spending multipliers for South Africa is even more scarce. A notable exception is Jooste et al. (2013), who found a (peak) spending multiplier of around 0.8 using a variety of methods. Jooste and Naraidoo (2017) extended the analysis using a DSGE model with fiscal foresight and found that household consumption (and aggregate output) increases when fiscal spending increases despite accounting for foresight. However, the result depends crucially on the inclusion of elastic labour supply and sticky wages in the model set-up. While not directly investigating spending multipliers, Kotze (2017) showed that an unexpected increase in the volatility of a particular fiscal instrument reduces economic output by close to a half a percentage point per annum and that the effects of such shocks last for almost three years. Table B.5 in Appendix B provides a selection of estimated government spending multipliers across both the developed and developing world.

Ramey (2016, 2019), among others, noted that there are two potential biases in the way that many researchers estimate spending multipliers which makes direct comparison difficult. First, following Blanchard and Perotti (2002), many researchers calculate multipliers by comparing the *peak* output response to the *initial* government spending shock. While this method is useful when directly comparing impulse responses, it is not the correct way to calculate multipliers and could produce biased estimates. As argued by Mountford and Uhlig (2009) and Fisher and Peters (2010), among others, the multiplier should instead be calculated as the ratio of the cumulative output response to the cumulative government spending response. This quantity more closely resembles its theoretical counterpart. In many cases, the Blanchard and Perotti method produces higher values for fiscal multipliers than the above-mentioned cumulative approach (Ramey, 2016).

The second potential bias stems from the *ex post* scaling of impulse responses to calculate spending multipliers. Most researchers estimating VARs specify the models in terms of natural logarithms. To calculate the implied multipliers, estimates are then multiplied by the sample mean of the ratio of GDP to government spending.[44] However, as shown in Owyang et al. (2013), this can lead to substantial biases, particularly in samples with significant trends in the GDP-to-spending ratio.

Finally, a relatively new strand of the literature investigates the possibility of state-dependent multipliers. Using a stock-and-flow-consistent CGE model with a detailed financial sector for South Africa, Makrelov et al. (2018) find peak spending multipliers of between 2 and 3.5 under conditions of a large negative output gap. Further empirical evidence for state-dependent multipliers can be found in, among others, Tagkalakis (2008), Callegari et al. (2012), Auerbach and Gorodnichenko (2012a,b, 2013, 2017), Bachmann and Sims (2012), Owyang et al. (2013), Gnip (2014), Fazzari et al. (2015), Figueres (2017), and Ramey and Zubairy (2018). Studies dealing with the zero lower bound include Eggertsson and Woodford (2003), Christiano et al. (2011), Eggertsson (2011), Woodford (2011), Fernández-Villaverde et al. (2015), and Leeper et al. (2017).

[44]This stems from the fact that $\frac{dY}{dG} \simeq \frac{dlnY}{dlnG}\frac{\bar{Y}}{G}$ where $\frac{\bar{Y}}{G}$ is the sample average of the GDP-to-government spending ratio.

Most of these studies into state-dependent multipliers found that spending multipliers are higher during times of slack and/or constrained monetary policy. Exceptions include Owyang et al. (2013) and Ramey and Zubairy (2018) who found no evidence for larger multipliers during recessions in the United States.[45] Caggiano et al. (2015) reconciled the apparent contradiction by showing that an increase in government spending during a downturn can accelerate the exit from the recession, with the duration of downturn being much shorter than assumed in most of the literature. As such, the discounted returns from an increase in government spending (i.e. present value multipliers) are lower and statistically equivalent to those in the boom phase. However, the authors showed that in extreme events (such as the GFC) the spending multiplier can be much larger. The bottom line is that not all recessions are alike, with increases in government spending delivering higher returns during deep recessions (Castelnuovo and Lim, 2019).

Tax shocks

Both time series models and estimated DSGE models have been used in the literature to investigate the effects of unanticipated tax shocks on macroeconomic outcomes. Table B.6 in Appendix B provides a brief overview of some of the results in the literature.

Blanchard and Perotti (2002) imposed an estimate of the elasticity of net taxes to GDP in an SVAR framework in order to identify exogenous shocks to net taxes and estimated an impact multiplier of -0.78. Several studies have followed in the footsteps of Blanchard and Perotti (2002) in using identified SVARS to estimate the impact of unanticipated tax shocks (see Table B.6). However, several authors have demonstrated that the results of these studies are highly dependent on the underlying elasticity assumptions. Caldara and Kamps (2017), for instance, demonstrated that small changes in the assumed tax revenue-to-GDP elasticity can result in significant changes in estimated multipliers.

While the SVARs are by far the most popular framework for measuring the impact of fiscal policy innovations, several authors have questioned its use as a tool for measuring the effects of tax policy (including Auerbach and Gorodnichenko, 2012b). First, unexpected changes in tax revenue may not be the result of an exogenous change in fiscal policy, but are more often than not the result of a change in the elasticity of tax revenues with respect to aggregate economic activity, i.e. the size of automatic stabilisers. Second, the effects of tax policy are expected to work through the structure of the tax system (i.e. marginal tax rates) rather than through the level of tax revenue. Finally, the identification of tax shocks in time series models depends crucially on the ability to purge innovations in tax revenues of automatic responses to output. As discussed in Blanchard and Perotti (2002) and mentioned above, the key assumption in this regard is the assumed elasticity of revenue with respect to output. Several authors, including Auerbach and Gorodnichenko (2012b), Ramey (2016) and Caldara and Kamps (2017), have pointed to the sensitivity of estimated tax multipliers to assumptions regarding this elasticity.

Mountford and Uhlig (2009) used sign restrictions to identify tax and spending shocks and estimate present-value multipliers. Their estimates suggest that the output response peaks (or bottoms) at -5 three years following a tax cut.

Using narrative methods, Romer and Romer (2010) identify tax shocks and obtain tax multipliers ranging between -2.5 and -3 at 3 years. Leigh (2010) used similar narrative measures to investigate the impact of tax increases across countries, while Cloyne (2013) applied this method to the United Kingdom. In a series of papers, Mertens and Ravn (2012, 2013, 2014) utilised

[45] Much less evidence is available for emerging and developing economies. Examples include Gnip (2014) who provides evidence for asymmetric multipliers in Croatia, and Jooste et al. (2013) who provide evidence for South Africa.

the Romer and Romer narrative series in creative ways. Mertens and Ravn (2012) decomposed the series into anticipated and unanticipated shocks, while Mertens and Ravn (2013) further decomposed the unanticipated parts of the series into changes relating to personal income tax and corporate income tax respectively. The authors found that while cuts in either tax have mild expansionary effects, cuts to personal income taxes induce a larger positive response than cuts to corporate tax rates.

Gechert (2015) conducted a meta-analysis of various types of multipliers across various identification methods and found tax and transfer multiplier of around 0.6 to 0.7. Importantly, the author highlighted the fact that estimated multipliers vary substantially with study design. As such, the influence of the particular design choice should be made clear when making policy recommendations based on the results.

The empirical literature on revenue multipliers in emerging- and low-income economies seem to suggest that tax multipliers are broadly similar to spending multipliers. For example, Ilzetzki (2011) found that spending multipliers range from 0.1 to 0.3, while short-term revenue multipliers are somewhat higher, lying between 0.2 and 0.4. Using a variety of methods, Jooste et al. (2013) found relatively large tax multipliers for South Africa. However, in general, tax multipliers appear to be smaller in emerging markets than in the developed world (see Table B.6).

3.3 Estimates of fiscal multipliers in South Africa

The empirical analysis of fiscal multipliers is based on three popular identification strategies. The first two approaches, namely the recursive and Blanchard and Perotti (2002) identification approaches, are implemented in a standard SVAR framework, while the third is based on the Uhlig (2005) sign-restrictions (SR) approach. Government spending and tax shocks are identified simultaneously while keeping in mind the associated caveats with identifying tax shocks within the (S)VAR framework.

3.3.1 The SVAR approach

The baseline reduced-form fiscal VAR model with p lags is described by the system

$$Y_t = \mu_0 + C(L)Y_{t-1} + \eta_t \tag{3.3.1}$$

where Y_t is the vector of endogenous variables, μ_0 is a constant, $C(L)$ is a polynomial lag operator, and η_t is the vector of reduced form residuals. Following Blanchard and Perotti (2002) and Caldara and Kamps (2017), among others, the baseline model contains three endogenous variables, namely government spending (g_t), output (y_t), and government tax revenue (t_t), that is $Y_t = [g_t \quad y_t \quad t_t]$.

The data for per capita log real GDP, log real government spending and log real taxes for the sample period 1970Q1 to 2018Q4 are sourced from the SARB Quarterly Bulletin.[46] Government spending is the sum of current spending (wage expenditure and expenditure on goods and services) and public sector fixed investment (general government and public corporations), while total taxes is the sum of personal income taxes (PIT), corporate income taxes (CIT),

[46]The Quarterly Bulletin contains data from various different sources for government variables, including National Revenue Fund data, Government Financial Statistics, and the System of National Accounts (SNA). In order to obtain as long a sample as possible, and given the fact that only aggregate variables are considered, data for this chapter was sourced from the SNA dataset.

value added tax (VAT), and other indirect taxes.[47] The tax variables are deflated using the implicit GDP deflator. All variables are expressed in natural logarithms and seasonally adjusted. Following Caldara and Kamps (2017), among others, all variables are detrended by removing a deterministic trend via OLS regression. The reduced form VAR contains four lags and a constant.

The structural form of the system to be estimated is:

$$A_0 Y_t = A_0 \mu_0 + A_0 C(L) Y_{t-1} + B\varepsilon_t \tag{3.3.2}$$

where $B\varepsilon_t = A_0\eta_t$. The matrix A_0 describes the contemporaneous relationships among the endogenous variables. The reduced form residuals η_t are correlated and, therefore, not purely exogenous. Following Blanchard and Perotti (2002) and Perotti (2005), among others, the set of equations can be written in matrix notation as:

$$\begin{pmatrix} 1 & -a_{gy} & -a_{gt} \\ -a_{yg} & 1 & -a_{yt} \\ -a_{tg} & -a_{ty} & 1 \end{pmatrix} \begin{bmatrix} \eta_t^g \\ \eta_t^y \\ \eta_t^t \end{bmatrix} = \begin{pmatrix} b_{gg} & 0 & b_{gt} \\ 0 & b_{yy} & 0 \\ b_{tg} & 0 & b_{tt} \end{pmatrix} \begin{bmatrix} \varepsilon_t^g \\ \varepsilon_t^y \\ \varepsilon_t^t \end{bmatrix} \tag{3.3.3}$$

Additional restrictions on the parameters in A_0 and B are required to achieve identification and recover the uncorrelated structural shocks.

Recursive identification

Following Caldara and Kamps (2008), among others, the first identification method considered is the recursive approach. In this approach, B is restricted to be a diagonal matrix, while A_0 is assumed to be lower-triangular with a unit diagonal. In the baseline model, government spending is ordered first, output is ordered second, and tax revenue is ordered third. As such, the relationship between the reduced-form innovations η_t and the structural shocks ε_t is given by the following expression:

$$\begin{pmatrix} 1 & 0 & 0 \\ -a_{yg} & 1 & 0 \\ -a_{tg} & -a_{ty} & 1 \end{pmatrix} \begin{bmatrix} \eta_t^g \\ \eta_t^y \\ \eta_t^t \end{bmatrix} = \begin{pmatrix} b_{gg} & 0 & 0 \\ 0 & b_{yy} & 0 \\ 0 & 0 & b_{tt} \end{pmatrix} \begin{bmatrix} \varepsilon_t^g \\ \varepsilon_t^y \\ \varepsilon_t^t \end{bmatrix} \tag{3.3.4}$$

The recursive approach implies that the specific ordering of the model variables have a causal interpretation. Ordering government spending first assumes that it does not react contemporaneously to any of the other endogenous variables in the system, in this case output and tax revenue. This can be justified by the fact that government spending is largely predetermined. As such, changes in government spending are, in general, unrelated to the current state of the economy. Output is ordered second, implying that output does not react within the quarter to tax shocks, but is allowed to respond to shocks to government spending. Finally, by placing taxes third in the VAR, it is assumed that tax revenues are affected contemporaneously by both government spending and output shocks. Ordering output before taxes is not a trivial assumption. However, the assumption can be justified on the grounds that shocks to output have a contemporaneous impact on the tax base and, hence, on tax revenue. A drawback of this particular ordering is that it rules out (potentially important) contemporaneous effects of tax shocks on output.

[47] See Table B.1 for detailed variable definitions and sources.

The Blanchard-Perotti (BP) approach

In contrast to the simple recursive structure embedded in the Cholesky decomposition, the identification approach introduced by Blanchard and Perotti (2002) relies on institutional information about the tax system and assumptions regarding the timing of tax collections to identify effects of automatic stabilizers on government revenue.

Unlike the recursive approach, the Blanchard-Perotti (BP) approach does not involve imposing (only) zero restrictions on the model parameters in order to achieve identification. In fact, a key element of the approach is imposition of additional non-zero restrictions on the contemporaneous relationships between variables. In the current application, as in their original paper, the output elasticity of tax revenue is calibrated using outside information. Following Perotti (2005), among others, this elasticity is estimated by regressing individual revenue items on their respective tax bases. An aggregate value for the output elasticity of government revenue equal to 1.27 is obtained, that is $a_{ty} = 1.27$[48] Furthermore, it is assumed that $a_{gy} = 0$. This assumption rests on the assumption that, because the government spending variable in question is defined net of transfers, government expenditure is acyclical. Additionally, it is assumed that fiscal variables do not react contemporaneously to shocks in other fiscal variables (i.e. $a_{gt} = a_{tg} = 0$). The latter two assumptions rest on the fact that governments cannot react within the same quarter to changes in the macroeconomic and/or policy environment due to the nature of fiscal policy decisions. Changes in fiscal policy requires the input and involvement of many different economic and political agents (including parliament, government, and civil society) and, therefore, can have long implementation lags. Finally, it is assumed that $b_{gt} = 0$, implicitly assuming that government spending decisions are taken before decisions on taxes.

In matrix notation, the set of restrictions can be expressed as:

$$\begin{pmatrix} 1 & 0 & 0 \\ -a_{yg} & 1 & -a_{yt} \\ 0 & -1.27 & 1 \end{pmatrix} \begin{bmatrix} \eta_t^g \\ \eta_t^y \\ \eta_t^t \end{bmatrix} = \begin{pmatrix} b_{gg} & 0 & 0 \\ 0 & b_{yy} & 0 \\ b_{tg} & 0 & b_{tt} \end{pmatrix} \begin{bmatrix} \varepsilon_t^g \\ \varepsilon_t^y \\ \varepsilon_t^t \end{bmatrix} \tag{3.3.5}$$

3.3.2 The Sign-restriction (SR) approach

Uhlig (2005) pioneered the use of the SR approach in identifying monetary policy shocks, while Mountford and Uhlig (2009) applied the approach to the identification of fiscal policy shocks. The SR approach entails imposing restrictions directly on the shape of structural impulse responses of the various model variables (Caldara and Kamps, 2008). This stands in contrast to the the two approaches discussed above which imposes linear restrictions on the contemporaneous relationships between model variables.

To illustrate the intuition behind the SR approach, consider a VAR(1) in reduced form (ignoring deterministic terms for ease of exposition):

$$Y_t = A_1 Y_{t-1} + \eta_t \tag{3.3.6}$$

Write equation (3.3.6) in its moving average representation:

$$Y_t = \sum_{i=0}^{\infty} \phi_i \eta_{t-i} \tag{3.3.7}$$

[48] See Appendix B for details on the calculation of the elasticity of government revenue with respect to output.

Here ϕ captures the reduced-form impulse responses with $\phi_o = I$ and $\phi_i = \sum_{j=1}^{i} \phi_{i-j} A_j$. A Cholesky decomposition with $\sum_\eta = PP'$ would obtain structural impulses, $\psi_i = \phi_i P$ since with $Y_t = \sum_{i=0}^{\infty} \phi_i P P^{-1} \eta_{t-i}$, the structural variance-covariance matrix $\sum_\varepsilon = P^{-1} E(\eta_t \eta_t') P^{-1'} = P^{-1} \sum_\eta P^{-1'} = P^{-1} P P' P^{-1'} = I$. In contrast to the Cholesky decomposition which imposes a recursive structure on the VAR, the SR approach identifies the structural shocks by imposing restrictions on the signs of ψ_i over a specific horizon i. Importantly, in contrast to other identification techniques, including the Cholesky decomposition, the contemporaneous impact matrix is not defined. As such, different orthogonalizations of the reduced form models could potentially be consistent with the sign restrictions. Importantly, the full set of orthogonalizations needs to be considered in order arrive at more reliable estimates and to satisfy the relatively broad set of identifying restrictions embodied in the approach. To obtain another orthogonal representation of the impulse responses, e.g. $\bar{\psi}_i$, one can simply multiply $\psi_i = \phi_i P$ by a random matrix Q with the property $Q'Q = I$, since then it still holds that $\bar{\sum}_\varepsilon = E(Q' P^{-1} \eta_t \eta_t' P^{-1'} Q) = I$ (Breitenlechner, 2019).

Mountford and Uhlig (2009) used a 10-variable VAR and identify four shocks, namely a business cycle shock, a monetary policy shock, a government spending shock, and a tax shock. In the baseline three-variable VAR used in this chapter, three shocks are identified, namely a business cycle shock, a government spending shock, and a tax shock. Following Mountford and Uhlig (2009) and Caldara and Kamps (2008), the business cycle shock is identified by the requirement that the impulse responses of output and taxes are positive for at least four quarters following the shock. Similarly, the government spending and tax shocks are separately identified by the requirement that their respective impulse responses are positive for at least four quarters following the shock. Finally, both fiscal shocks are required to be orthogonal to the business cycle shock. In practice, this assumption ensures that whenever taxes and output move in the same direction, the co-movement is attributed to a change in the business cycle, i.e. it eliminates cases where positive output responses are erroneously attributed to positive tax shocks (Caldara and Kamps, 2008).

Table 3.1 shows the sign restrictions on the impulse responses for each identified shock. A '+' means that the relevant impulse is restricted to be positive for four quarters following the shock.

Table 3.1: Identifying sign restrictions

	Real GDP	Government spending	Tax revenue
Business cycle shock	+		+
Government spending shock		+	
Tax shock			+

Estimation is carried out using Bayesian techniques as implemented in the ZeroSignVAR package for Matlab (Breitenlechner, 2019).[49]

3.4 Baseline results

This section presents empirical results for pure government spending and tax shocks in the baseline three-variable VAR.[50] Following Caldara and Kamps (2008), among others, the impulse responses in the rest of the chapter are scaled as follows: The responses of the endogenous

[49] The algorithm is based on Arias et al. (2014).

[50] That is, results are shown for shocks to one fiscal variable at a time without constraining the response of the other fiscal variable(s).

variables are transformed so as to give the rand response of each variable to a one rand shock in one of the fiscal variables. To this end, following the procedure of Blanchard and Perotti (2002), the original impulse responses are first divided by the standard deviation of the fiscal shock in order to have shocks of size one per cent. These impulse responses are then divided by the sample mean of the ratio of the macroeconomic variable of interest and the shocked fiscal variable. The rescaled impulses can be interpreted as constant, non-accumulated rand multipliers. That is, the impulse response functions (and the associated multipliers) demonstrate the rand change in government spending, output and taxes over time after a R1 increase in government spending or taxes.[51]

3.4.1 Pure spending shock

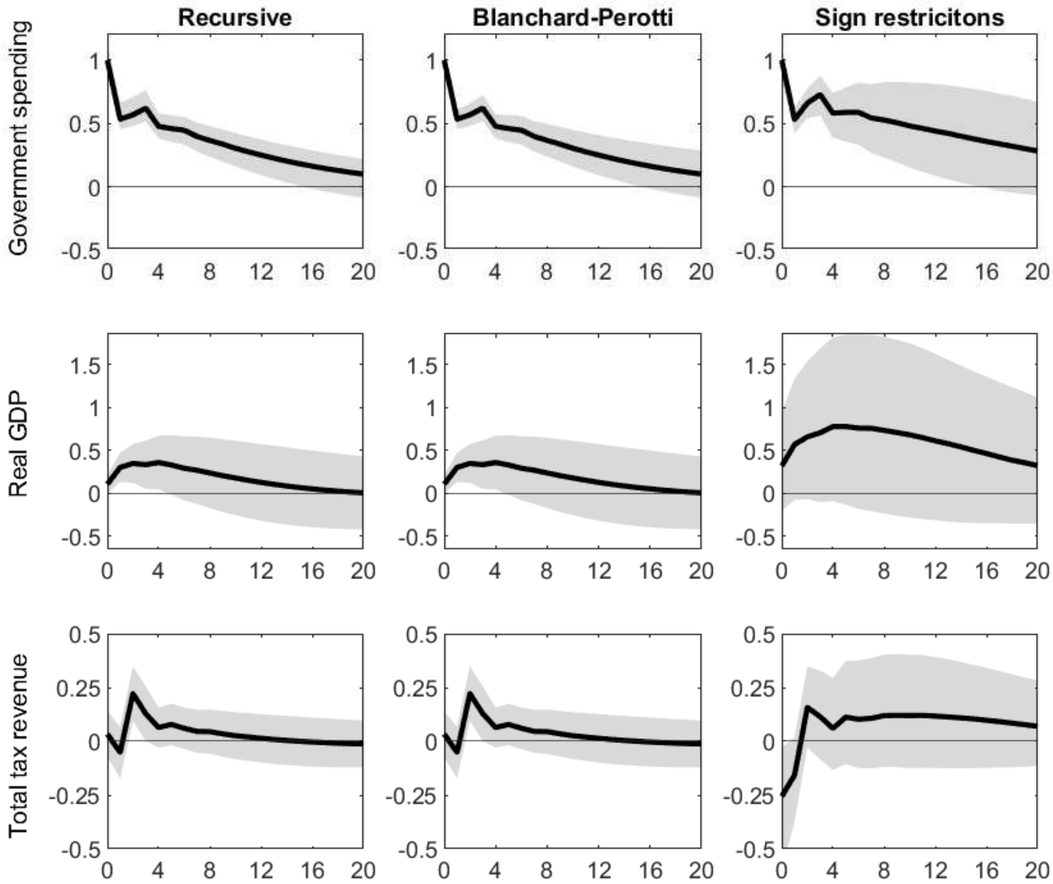
Figure 3.1 presents the impulse responses for a pure spending shock, with each column representing a different identification approach. The identified government spending shock is similar across all three identification approaches. Under the recursive and BP approaches, impulse responses are virtually identical. This follows from the fact that the spending shock is identified in the same way for both approaches, namely by ordering government spending first in the SVAR. The results also show that taxes only partly offset the increase in government spending, suggesting that the pure spending shock can be interpreted as a deficit-financed spending shock. For all approaches, real GDP persistently increases following the government spending shock, displaying a hump-shaped pattern. Table 3.2 presents implied spending multipliers associated with the different identification schemes. For the recursive and BP approaches, the implied impact multiplier measures 0.11. The spending multiplier peaks at around 0.36 in the fourth quarter after the shock. For the SR approach, both the impact and peak multipliers are significantly larger, measuring 0.32 and 0.78 (four quarters after the shock) respectively. However, the estimates are much less precise as reflected in the wider confidence bands.

3.4.2 Pure tax shock

Figure 3.2 presents the impulse responses for a pure tax shock, while Table 3.2 again presents implied multipliers. Results for both the BP and SR approaches suggest that unanticipated increases taxes have strong distortionary effects. In the case of the BP approach, the decline in real GDP peaks at around 0.65 after 10 quarters. As was the case for the pure spending shock, the response is larger under the SR approach, with the decline in real GDP peaking at 0.78 after 10 quarters. In contrast, there is not statistically significant GDP response under the recursive identification approach. The tax response peaks in the quarter when the shock occurs and then monotonically declines, turning negative after about eight to 12 quarters as the decline in output weighs on tax receipts. Government spending declines over the medium term under all three identification approaches, although the initial response is positive (and significant) under the SR approach. Importantly, over the medium term tax shocks have a much larger effect on real GDP than government spending shocks.

[51] Since the data enter the estimated equations in logs, the estimated IRFs are scaled by the sample average values to convert percent changes into rand changes.

Figure 3.1: Response to a pure spending shock (baseline three-variable VAR)

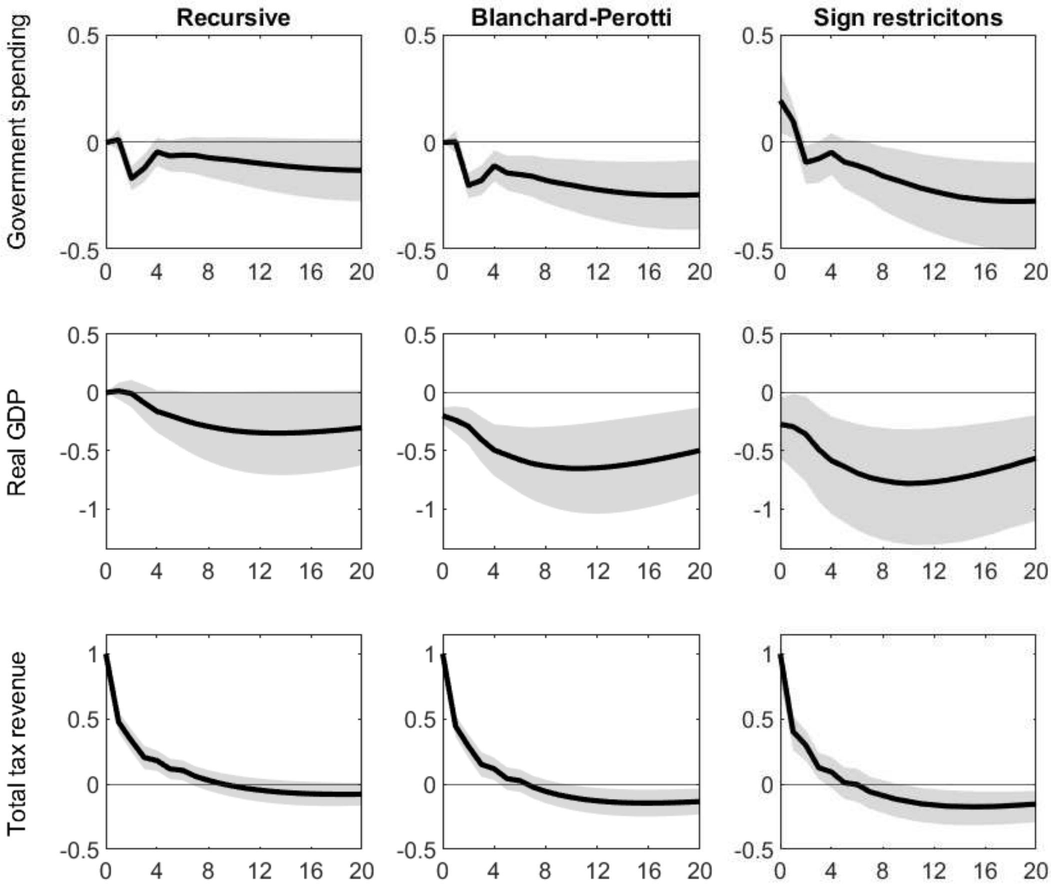


Note: The figures show impulse responses to a R1 increase in government spending. For the recursive and BP approach, shaded areas represent 90% confidence intervals. For the SR approach, the shaded area represents 90% of the identified posterior distribution.

Table 3.2: Output multipliers in the baseline model

	Q1	Q4	Q8	Q12	Q20	Maximum
Government spending multiplier						
Recursive	0.11	0.36	0.24	0.13	0.01	0.36 (Q4)
Blanchard-Perotti	0.11	0.36	0.24	0.13	0.01	0.36 (Q4)
Sign restriction	0.32	0.78	0.73	0.61	0.32	0.78 (Q4)
Tax multiplier						
Recursive	0.00	-0.16	-0.29	-0.35	-0.30	-0.35 (Q12)
Blanchard-Perotti	-0.20	-0.50	-0.63	-0.65	-0.50	-0.65 (Q10)
Sign restriction	-0.27	-0.59	-0.76	-0.77	-0.56	-0.78 (Q10)

Figure 3.2: Response to a pure tax shock (baseline three-variable VAR)



Notes: The figures show impulse responses to a R1 increase in taxes. For the recursive and BP approach, shaded areas represent 90% confidence intervals. For the SR approach, the shaded area represents 90% of the identified posterior distribution.

3.4.3 Alternative multiplier definition

The calculation of the fiscal multipliers in Table 3.2 is based on the Blanchard and Perotti (2002) approach, i.e. multipliers are computed by comparing the output response in a specific period to the *initial* government spending shock. While is useful way to directly compare impulse responses, as mentioned earlier, the multiplier should instead be calculated as the ratio of the cumulative output response to the cumulative government spending response. This quantity more closely resembles its theoretical counterpart.

To that end, cumulative present-value multipliers for the baseline are presented in Table 3.3. These present-value multipliers are calculated as follows (following Mountford and Uhlig, 2009, among others):

$$\text{Present-value multiplier at horizon } k = \frac{\sum_{j=0}^{k}(1+r)^{-j}y_{t+j}}{\sum_{j=0}^{k}(1+r)^{-j}f_{t+j}}\frac{1}{f/y} \tag{3.4.1}$$

where y_{t+j} is the response of real GDP at period j, f_{t+j} is the response of the fiscal variable at period j, and r is the average nominal policy interest rate (the main repurchase, or repo, rate) over the sample. As before, the responses are scaled by f/y (the ratio of the fiscal variable to real GDP evaluated at the sample mean).

The multipliers in Table 3.3 show that, in present value terms, tax shocks have a much greater effect on real GDP than government spending shocks. In fact, apart from over the long term under the SR approach, present-value spending multipliers never exceed one.

Table 3.3: Present-value output multipliers

	Q1	Q4	Q8	Q12	Q20
Government spending multiplier					
Recursive	0.11	0.42	0.49	0.50	0.49
Blanchard-Perotti	0.11	0.42	0.49	0.50	0.49
Sign restriction	0.32	0.82	0.97	1.03	1.06
Tax multiplier					
Recursive	0.00	-0.09	-0.32	-0.55	-0.85
Blanchard-Perotti	-0.20	-0.70	-1.38	-2.05	-3.02
Sign restriction	-0.27	-0.90	-1.80	-2.78	-4.28

3.5 Alternative specifications

This section extends the baseline three-variable VAR to gauge the impact of fiscal shocks on other macroeconomic variables of interest, including private consumption and investment. Furthermore, the baseline VAR is extended to include prices and interest rates in order to control for the effects of monetary policy decisions.

3.5.1 Effects of fiscal shocks on private consumption and investment

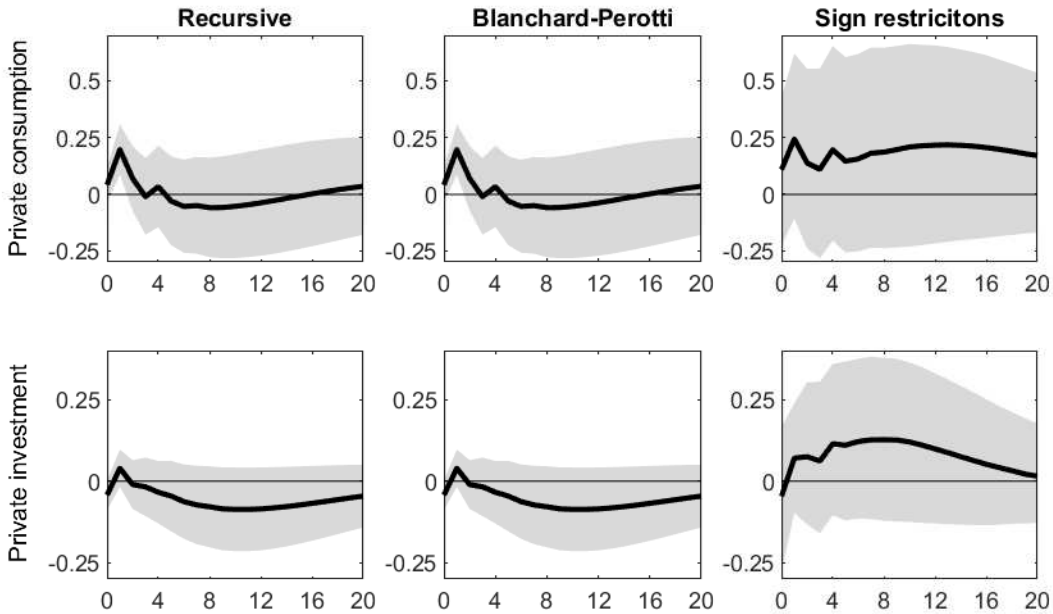
In order to gauge the impact of fiscal shocks on private consumption and investment, the baseline three-variable VAR is extended with consumption and investment in turn ordered after output in the VAR. That is $Y_t = [g_t \quad y_t \quad x_t \quad t_t]$ where $x_t \in \{c_t, i_t\}$. Placing private consumption or private investment after output assumes that it does not react contemporaneously to taxes, but that it is contemporaneously affected by government spending and output shocks.

As before, additional restrictions are required to achieve identification. The recursive identification approach identifies structural shocks by imposing a recursive structure on matrix A_0 in equation (3.3.2), i.e. A_0 is lower triangular, while the matrix B is assumed to be diagonal. Under the BP approach, the elasticity of tax revenue with respect to consumption and investment is estimated analogously to that of output, as detailed in Section 3.3.1.[52] The elasticity of consumption and investment with respect to taxes is estimated directly in the VAR framework. Under the SR approach, an additional identifying assumption is imposed in that the business cycle shock is now identified by the requirement that the impulse responses of output, taxes and the additional output component (consumption or investment) are positive for at least four quarters after the shock.

The impulse responses for private consumption and private investment following pure spending and tax shocks are presented in Figure 3.3 and Figure 3.4 respectively, while Table 3.4 provides present-value multipliers. The impulse responses are rescaled as before: the original impulse responses are first divided by the standard deviation of the fiscal shock in order to have shocks of size one per cent. These impulse responses are then divided by the sample mean of the ratio of the respective variable and the shocked fiscal variable.

[52]Consumption and investment elasticities, as well as details with respect to the full model specification, can be found in Appendix B.

Figure 3.3: Response to a pure spending shock (expanded four-variable VAR)

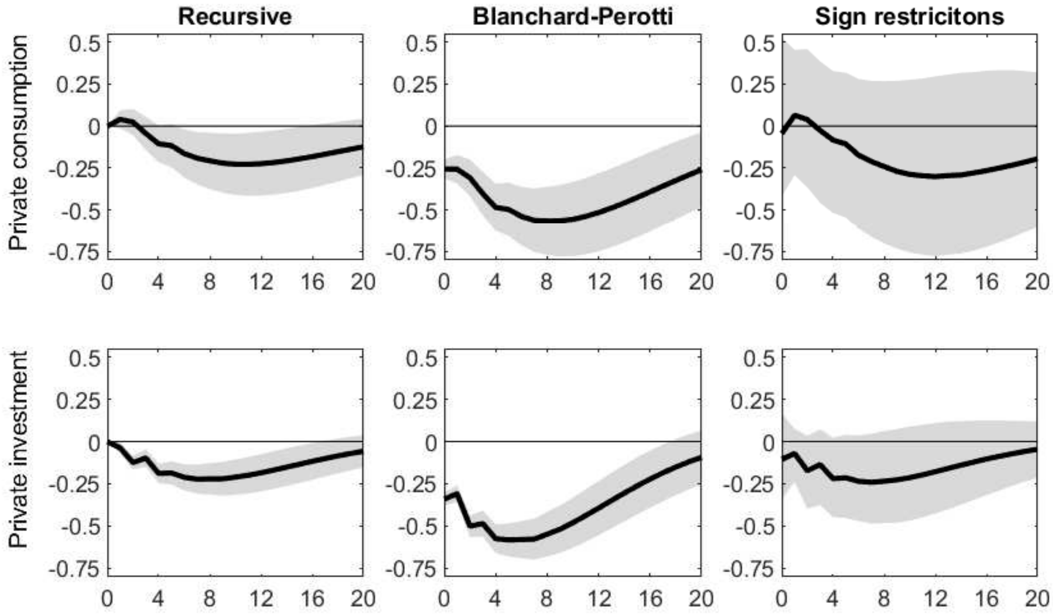


Note: The figures show impulse responses to a R1 increase in government spending. For the recursive and BP approach, shaded areas represent 90% confidence intervals. For the SR approach, the shaded area represents 90% of the identified posterior distribution.

Consumption responds positively to a government spending shock under all three identification approaches (see Figure 3.3). However, the positive response is short-lived under the recursive and BP schemes, with the response turning negative (and insignificant) after around four quarters. Under both the recursive and BP approaches, the implied impact multiplier is 0.04, while the spending multiplier peaks at around 0.20 in the second quarter after the shock. In contrast, under the SR approach real private consumption persistently increases following the government spending shock, although the wider confidence bands points to significant uncertainty. That being said, the implied impact multiplier measures 0.11 and the multiplier peaks at around 0.24 in the first quarter after the shock. These results echo findings in the broader empirical literature which point to positive consumption responses to government spending shocks. However, as mentioned above, these results appear to be at odds with theoretical predictions and results from the DSGE literature which posit a negative response of consumption to government spending shocks. The final chapter in this thesis attempts to shine further light on this divergence. Turning to the response of private investment, apart from a small positive response on impact, the response of private fixed investment to a shock to government spending is negative under both the recursive and BP identification approaches. While the response is positive under the SR approach, the wider confidence bands points to significant uncertainty.

Figure 3.4 presents the impulse responses for private consumption and private investment following a pure tax shock. The tax shock has a significant distortionary effect on both private consumption and investment, with the response particularly strong under the BP identification approach. The decline in consumption peaks at 0.57 in the eighth quarter following the shock, while the negative response for investment is similar with a peak decline of 0.58 in the fifth quarter following the shock. Under the SR approach, the decline in consumption peaks at around 0.30 12 quarters after the shock. The responses of investment under the recursive and SR identification approaches are broadly similar, with the decline peaking at just over 0.20 eight quarters after the shock.

Figure 3.4: Response to a pure tax shock (expanded four-variable VAR)



Note: The figures show impulse responses to a R1 increase in taxes. For the recursive and BP approach, shaded areas represent 90% confidence intervals. For the SR approach, the shaded area represents 90% of the identified posterior distribution.

Table 3.4: Present-value consumption and investment multipliers

	Q1	Q4	Q8	Q12	Q20
Government spending multiplier					
Private consumption					
Recursive	0.04	0.11	0.05	0.03	0.03
Blanchard-Perotti	0.04	0.11	0.05	0.03	0.03
Sign restriction	0.11	0.22	0.25	0.28	0.31
Private investment					
Recursive	-0.04	-0.02	-0.05	-0.08	-0.10
Blanchard-Perotti	-0.04	-0.02	-0.05	-0.08	-0.10
Sign restriction	-0.05	0.07	0.11	0.13	0.13
Tax multiplier					
Private consumption					
Recursive	0.00	-0.02	-0.19	-0.34	-0.50
Blanchard-Perotti	-0.26	-0.80	-1.63	-2.58	-4.05
Sign restriction	-0.04	-0.01	-0.19	-0.38	-0.63
Private investment					
Recursive	0.00	-0.17	-0.36	-0.51	-0.62
Blanchard-Perotti	-0.34	-1.22	-2.74	-5.08	-10.99
Sign restriction	-0.10	-0.28	-0.46	-0.58	-0.66

According to Table 3.4, present-value consumption multipliers following a shock to government spending is positive across all horizons, but the response is relatively subdued. In contrast, private investment multipliers are small and insignificant, with only the SR approach yielding positive multipliers. Tax multipliers are negative across the board and larger in absolute terms than spending multipliers. This confirms the finding of Section 3.4 that tax shocks are highly distortionary and have a larger effect on real outcomes than unanticipated shocks to government spending.

3.5.2 Effects of fiscal shocks when controlling for monetary policy

The baseline three-variable VAR is extended to include inflation and a measure of the short-term interest rate to control for the effects of monetary policy. Inflation is ordered after output but before taxes, while the short-term interest rate is ordered last, i.e. $Y_t = [g_t \quad y_t \quad \pi_t \quad t_t \quad r_t]$. The ordering assumes that inflation does not respond contemporaneously to taxes and the interest rate, while it does respond contemporaneously to government spending and output. The ordering further assumes that taxes do not respond contemporaneously to the short-term interest rate, while it as assumed that the interest rate responds contemporaneously to all variables in the system. The measure of the inflation is the quarter-on-quarter percentage change in the CPI index, while the measure of the short-term interest rate is the main repurchase (or repo) rate.

Under the recursive identification scheme, the normal zero-restrictions apply (i.e. A_0 is lower triangular an B is diagonal in the AB model). However, additional restrictions are required under the BP approach.

The set of equations (including the inherited identifying assumptions from the baseline VAR) can be expressed in matrix form as:

$$\begin{pmatrix} 1 & 0 & -a_{g\pi} & 0 & -a_{gr} \\ -a_{yg} & 1 & 0 & -a_{yt} & 0 \\ -a_{\pi g} & -a_{\pi y} & 1 & -a_{\pi t} & 0 \\ 0 & -1.27 & -a_{t\pi} & 1 & -a_{tr} \\ -a_{rg} & -a_{ry} & -a_{r\pi} & -a_{rt} & 1 \end{pmatrix} \begin{bmatrix} \eta_t^g \\ \eta_t^y \\ \eta_t^\pi \\ \eta_t^t \\ \eta_t^r \end{bmatrix} = \begin{pmatrix} b_{gg} & 0 & 0 & 0 & 0 \\ 0 & b_{yy} & 0 & 0 & 0 \\ 0 & 0 & b_{\pi\pi} & 0 & 0 \\ b_{tg} & 0 & 0 & b_{tt} & 0 \\ 0 & 0 & 0 & 0 & b_{rr} \end{pmatrix} \begin{bmatrix} \varepsilon_t^g \\ \varepsilon_t^y \\ \varepsilon_t^\pi \\ \varepsilon_t^t \\ \varepsilon_t^r \end{bmatrix} \tag{3.5.1}$$

Four additional restrictions are required to identify the structural shocks in (3.5.1). First, given that interest paid and received by the government is excluded from the fiscal variable definitions, it is assumed that $a_{gr} = a_{tr} = 0$. The elasticity of government spending with respect to inflation ($a_{g\pi}$) is calculated as the weighted average of the elasticities of the different spending components. The wage component of government spending is fixed within the quarter, implying that the elasticity with respect to inflation is -1. While prices of goods and services purchased do evolve with inflation, a portion of aggregate spending will be fixed as it is determined through the budgetary process. It is assumed that this fixed portion of total spending does not react to inflation developments (elasticity equal to -1), while the remainder will mirror developments in inflation (elasticity equal to 0). As a compromise, the elasticity of real spending on goods and services to inflation is set to -0.5. Similarly, while government investment spending might be largely fixed within a quarter, a portion might be more closely indexed to inflation. As such, the elasticity of real public sector investment spending to inflation is also set to -0.5. The weighted average of these three elasticities implies that the elasticity of real government spending with respect to inflation ($a_{g\pi}$) is set equal to -0.79.

Finally, the price elasticity of tax revenue is set equal to 0.19 ($a_{t\pi} = 0.19$). The price elasticity of personal income tax can be estimated by subtracting one from the elasticity of personal taxes to average earnings (Perotti, 2005). As shown in Appendix B, this elasticity is estimated at 1.58. Subtracting one from this estimate implies a price elasticity of 0.58. Corporate taxes have a very uncertain relationship with prices in both directions and so a price elasticity of zero is assumed. As a large share of indirect taxes (including VAT) is *ad valorem*, a zero elasticity of real indirect tax revenue to inflation is assumed. The weighted average of these individual elasticities is then equal to 0.19.

In matrix form, the set of restrictions can be expressed as:

$$\begin{pmatrix} 1 & 0 & 0.79 & 0 & 0 \\ -a_{yg} & 1 & 0 & -a_{yt} & 0 \\ -a_{\pi g} & -a_{\pi y} & 1 & -a_{\pi t} & 0 \\ 0 & -1.27 & -0.19 & 1 & 0 \\ -a_{rg} & -a_{ry} & -a_{r\pi} & -a_{rt} & 1 \end{pmatrix} \begin{bmatrix} \eta_t^g \\ \eta_t^y \\ \eta_t^\pi \\ \eta_t^t \\ \eta_t^r \end{bmatrix} = \begin{pmatrix} b_{gg} & 0 & 0 & 0 & 0 \\ 0 & b_{yy} & 0 & 0 & 0 \\ 0 & 0 & b_{\pi\pi} & 0 & 0 \\ b_{tg} & 0 & 0 & b_{tt} & 0 \\ 0 & 0 & 0 & 0 & b_{rr} \end{pmatrix} \begin{bmatrix} \varepsilon_t^g \\ \varepsilon_t^y \\ \varepsilon_t^\pi \\ \varepsilon_t^t \\ \varepsilon_t^r \end{bmatrix} \quad (3.5.2)$$

Additional identifying restrictions are also required under the SR approach. The set of identified shocks now includes a monetary policy shock. The monetary policy shock is identified by the requirement that the impulse response of the interest rate is positive for at least four quarters following the shock and that the impulse response of inflation is negative for at least four quarters after the shock (see Table 3.5).

Table 3.5: Identifying sign restrictions in the extended five-variable model

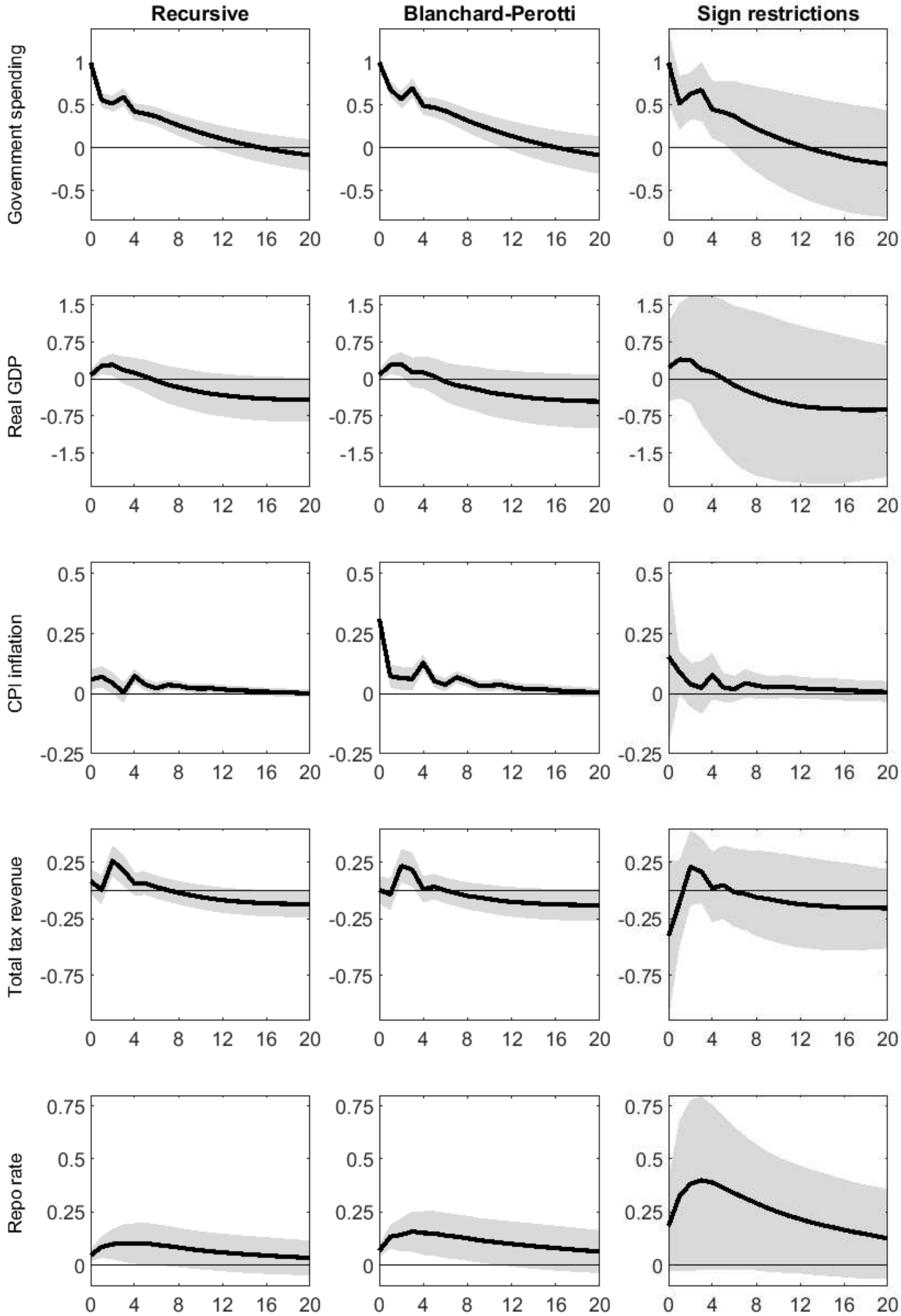
	Real GDP	Government spending	Inflation	Tax revenue	Interest rate
Business cycle shock	+			+	
Monetary policy shock			-		+
Government spending shock		+			
Tax shock				+	

The impulse responses for pure spending and tax shocks are presented in Figure 3.5 and Figure 3.6 respectively. The impulse responses for output and the fiscal variables are scaled as before. The responses of inflation give the percentage change in response to a one-percent fiscal shock. The responses of the interest rate are expressed as change in percentage points for a one-percent fiscal shock.

As was the case under the baseline specification, real GDP responds positively to a government spending shock under all three identification approaches (see Figure 3.5). However, unlike in the baseline model, the positive response is short-lived, with the output response turning negative (and insignificant) after around four quarters. The spending shock results in a positive inflation response, which, together with the initial positive output response, results in a statistically significant interest rate response. This has the effect of lowering inflation but also dampening the output response following a positive government spending shock. Under the recursive and BP identification schemes, the output response peaks at around 0.30 in the second quarter after the shock. Under the SR approach, the response peaks at 0.40 in the second quarter, just over half the size of the peak response under the baseline specification.

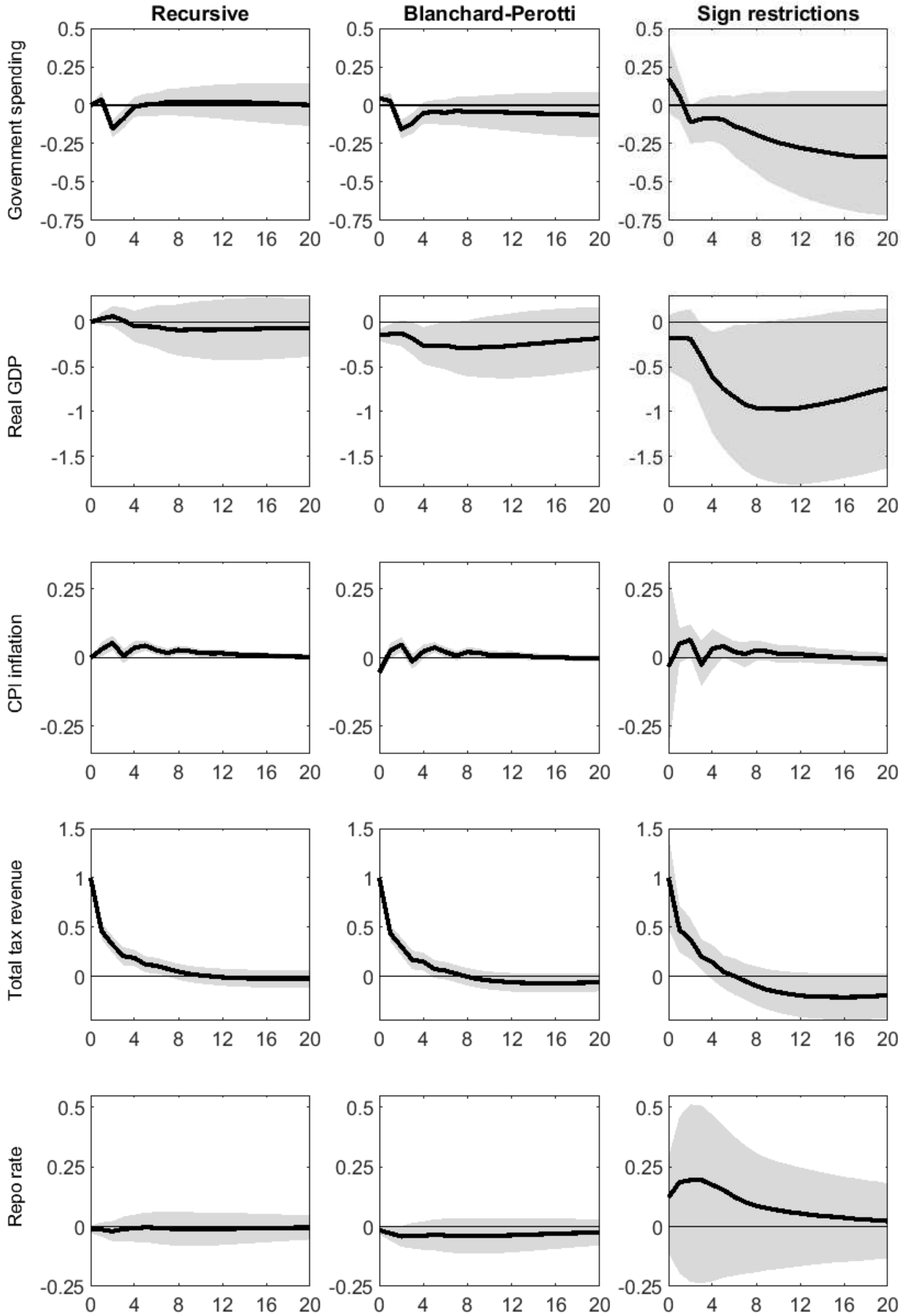
Similarly, the output response to a pure tax shock is also smaller when including monetary variables in the SVAR (see Figure 3.6). Under the recursive and BP approaches, the decline in real GDP peaks at 0.09 and 0.29, respectively, in the eighth quarter after the shock versus the 0.65 peak decline registered in the baseline model. The drop in output results in a marginal decline in inflation which induces a decline in the policy rate, supporting real GDP growth and limiting the negative response to a tax shock. The subdued response from government spending following the tax shock also contributes to the more muted output response. In contrast, under the SR approach, output responds much the same as in the three-variable baseline VAR.

Figure 3.5: Response to a pure spending shock (expanded five-variable VAR)



Note: The figures show impulse responses to a R1 increase in government spending. The responses of inflation give the percentage change in response to a one-percent fiscal shock. The responses of the interest rate are expressed as change in percentage points for a one-percent fiscal shock. For the recursive and BP approach, shaded areas represent 90% confidence intervals. For the SR approach, the shaded area represents 90% of the identified posterior distribution.

Figure 3.6: Response to a pure tax shock (expanded five-variable VAR)



Note: The figures show impulse responses to a R1 increase in taxes. The responses of inflation give the percentage change in response to a one-percent fiscal shock. The responses of the interest rate are expressed as change in percentage points for a one-percent fiscal shock. For the recursive and BP approach, shaded areas represent 90% confidence intervals. For the SR approach, the shaded area represents 90% of the identified posterior distribution.

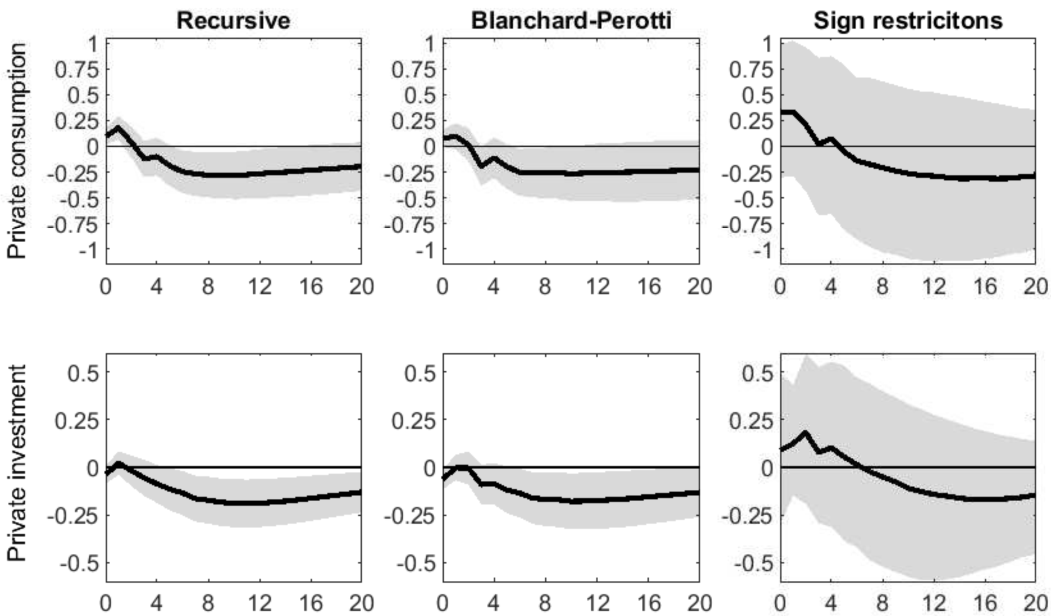
Under the SR approach, the impact multiplier measures -0.18, with decline in real GDP peaking at 0.97 in the tenth quarter after the shock. One reason for the discrepancy might be the fact that the SR approach is relatively agnostic, imposing less restrictive identifying assumptions. This highlights the importance of the elasticity assumptions embedded in the BP approach.

Present-value multipliers are presented in Table B.4 in Appendix B. Output multipliers are based on the five-variable monetary policy VAR. Present-value output multipliers are smaller across all horizons than in the three-variable baseline model, with medium-term multipliers turning negative. For the recursive and BP approach, tax multipliers are also smaller in absolute terms, but broadly in line with baseline multipliers under the SR identification approach.

Finally, the five-variable monetary policy VAR is extended by including private consumption and private investment in turn, ordered third in the extended VAR.[53] The impulse responses for private consumption and investment are presented in Figure 3.7 and Figure 3.8, while present value multipliers are provided in Table B.4 in Appendix B.

Similar to the results for real GDP, the inclusion of monetary policy variables in the extended VAR results in more muted responses from consumption and investment following a government spending shock. This is particularly true under the SR approach where the consumption response turns negative after four quarters as opposed to remaining positive over the entire horizon as was the case in the baseline model. The present-value multipliers in Table B.4 confirm the more muted (and negative in some cases) response for both consumption and investment. For the tax shock, the negative response of both consumption and investment is also more subdued under the recursive and BP identification approaches. However, as before, the impulse responses and present-value multipliers are broadly in line with the base case under the SR approach.

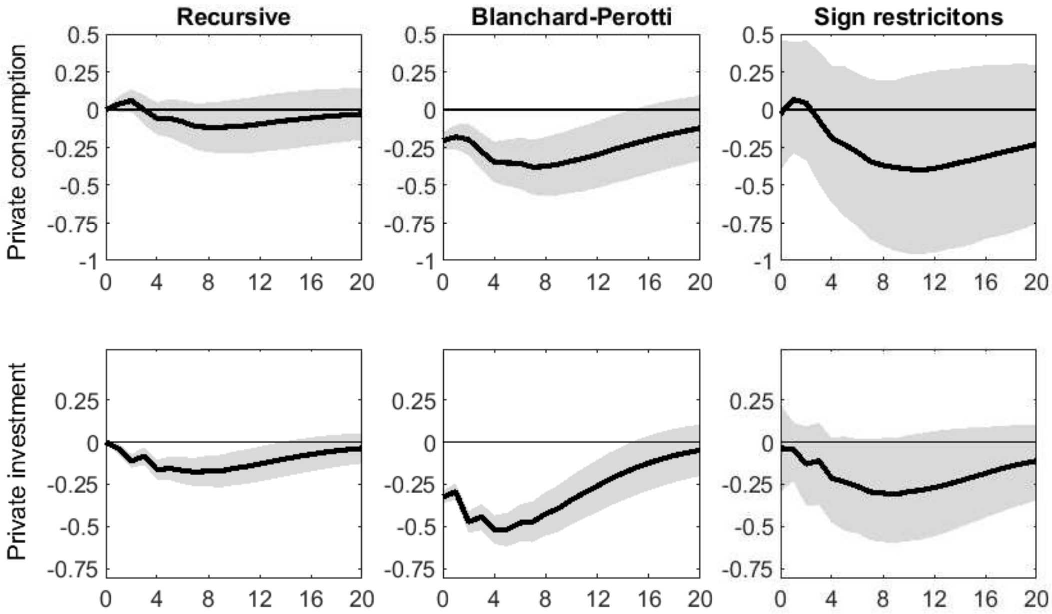
Figure 3.7: Response to a pure spending shock (expanded six-variable VAR)



Note: The figures show impulse responses to a R1 increase in government spending. For the recursive and BP approach, shaded areas represent 90% confidence intervals. For the SR approach, the shaded area represents 90% of the identified posterior distribution.

[53]Consumption and investment elasticities, as well as details with respect to the full model specification, can be found in Appendix B.

Figure 3.8: Response to a pure tax shock (expanded six-variable VAR)



Note: The figures show impulse responses to a R1 increase in government spending. For the recursive and BP approach, shaded areas represent 90% confidence intervals. For the SR approach, the shaded area represents 90% of the identified posterior distribution.

3.6 State dependent multipliers

During the last decade, the literature on the effects of fiscal shocks on macroeconomic outcomes has explored the possibility that fiscal multipliers might differ depending on the state of the economy and/or monetary policy. As mentioned above, the GFC renewed interest in the ability of activist fiscal policy to lift the global economy out of the crisis-induced recession in an environment where monetary policy had run out of room (i.e. policy rates hit the zero lower bound). One strand of this literature investigates the possibility that fiscal multipliers are higher during times of economic slack relative to periods of expansion (for example, Barro and Redlick, 2011; Auerbach and Gorodnichenko, 2012a,b). Another strand considers how the stance of monetary policy affects government spending multipliers, with specific reference to the implications of hitting the zero lower bound (see, for example, Cogan et al., 2010; Christiano et al., 2011; Coenen et al., 2012).

This section explores the possibility that fiscal multipliers differ across the cycle within the South African context. The approach follows that of Auerbach and Gorodnichenko (2012b) as applied in Auerbach and Gorodnichenko (2012a) and Ramey and Zubairy (2018).[54]

In their original paper, Auerbach and Gorodnichenko (2012b) developed a smooth transition vector autoregression (STVAR) model based on smooth transition autoregressive (STAR) models. The basic specification was:

$$Y_t = (1 - F(z_{t-1}))\,\Pi_E(L)Y_{t-1} + F(z_{t-1})\Pi_R(L)Y_{t-1} + u_t \tag{3.6.1}$$

[54]Note that the terms recession and expansion have varying definitions in the literature. In the context of this chapter, the terms 'recession' and 'downturn/downswing' are used interchangeably, as are the terms 'expansion' and 'upturn/upswing'.

with

$$u_t \sim N(0, \Omega) \tag{3.6.2}$$

$$\Omega_t = \Omega_E\left(1 - F(z_{t-1})\right) + \Omega_R F(z_{t-1}) \tag{3.6.3}$$

$$F(z_t) = \frac{exp(-\gamma z_t)}{1 + exp(-\gamma z_t)}, \quad \gamma > 0 \tag{3.6.4}$$

where $Y_t = [g_t \quad t_t \quad y_t]'$ is a vector of the logarithms of real per capita government spending, taxes, and output, z is an indicator of the state of the economy, and $\Pi_i(L)$ and $\Omega_i(L)$ represent the VAR coefficients and variance- covariance matrix of disturbances in the two regimes. The weights assigned to each regime varies between zero and one according to the state if the economy, z, which was calculated as the seven-period moving average of real GDP growth.

Auerbach and Gorodnichenko (2012a) extended the approach to cover several OECD countries. However, instead of estimating an STVAR as in the earlier paper, the authors employ the local projection method. The single-equation local projection method (advocated by Jordà (2005), Stock and Watson (2007), and others) presents a flexible alternative that does not impose the implicit dynamic restrictions inherent in vector autoregressions, while at the same time being able to easily accommodate non-linearities of the type under consideration.

The method simply requires estimation of a series of regressions for each horizon h for each variable. In the simple linear case, this takes the following form (following Ramey and Zubairy, 2018):

$$y_{t+h} = \alpha_h + \Pi_h(L)x_{t-1} + \beta_h \text{shock}_t + \varepsilon_{t+h} \tag{3.6.5}$$

where y_t is the variable of interest, x_t is a vector of control variables, $\Pi_h(L)$ is the coefficients related to the lagged control variables, and shock_t is a measure of the fiscal policy shock.[55] The coefficient β_h gives the response of y at time $t+h$ to the shock at time t. Thus, impulse responses can be constructed as a sequence of the estimated β_h's. This is different to the standard method of constructing impulse response functions whereby the parameters of the VAR are estimated for horizon 0 and then used to iterate forward to construct impulse responses (Ramey and Zubairy, 2018).

This method is easily adapted to estimating a state-dependent model (using a similar notation than in equation (3.6.1)):

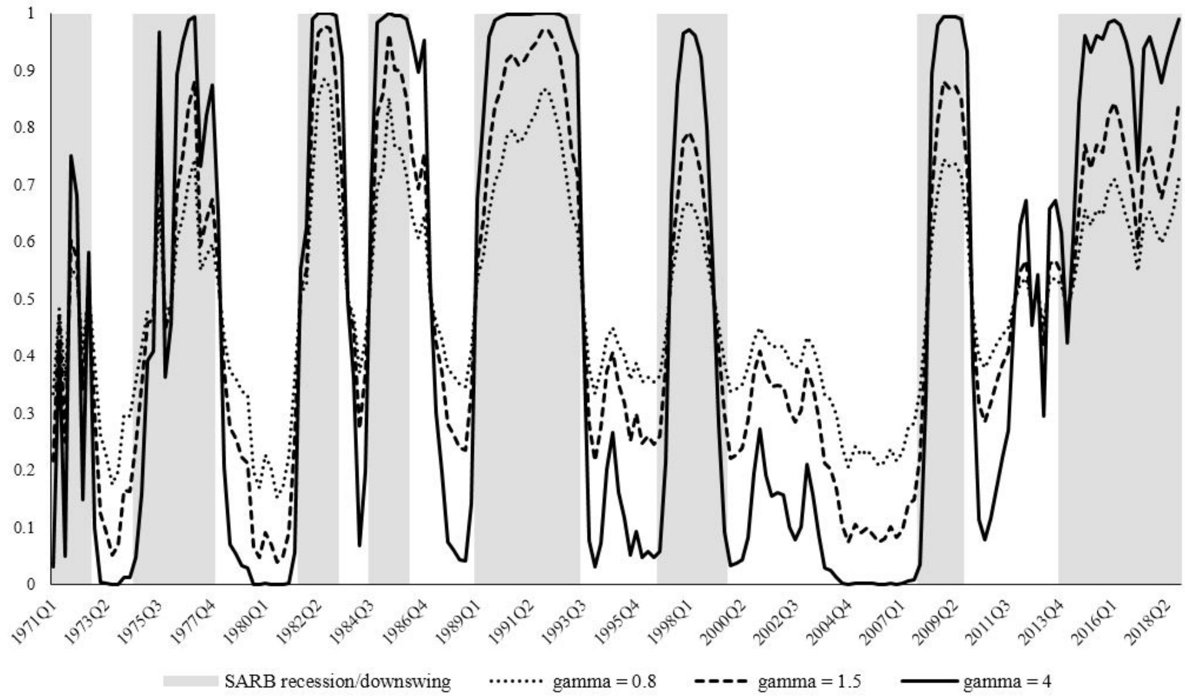
$$\begin{aligned} y_{t+h} = (1 - F(z_{t-1}))\left[\alpha_{E,h} + \Pi_{E,h}(L)x_{t-1} + \beta_{E,h}\text{shock}_t\right] \\ + F(z_{t-1})\left[\alpha_{R,h} + \Pi_{R,h}(L)x_{t-1} + \beta_{R,h}\text{shock}_t\right] + \varepsilon_{t+h} \end{aligned} \tag{3.6.6}$$

Therefore, the forecast of y_{t+h} is allowed to differ according to the state of the economy when the shock hit. As in Ramey and Zubairy (2018), the Newey-West correction is used to account for the serial correlation in the error terms induced by the successive leading of the dependent variable.

According to Auerbach and Gorodnichenko (2012a), the local projection method has several advantages over the STVAR approach when it comes to estimating state-dependent multipliers. First, it involves only linear estimation in the case where γ in expression (3.6.4) is fixed (as

[55] In Ramey and Zubairy (2018) the shock vector is either the estimated military spending news series or a measure of the Blanchard-Perotti shock.

Figure 3.9: SARB dates and weight on recession regime $F(z)$



it is in Auerbach and Gorodnichenko, 2012b and in this application). Second, it reduces the dimensionality of the problem given the fact that one need not estimate equations for variables other than the variable of interest (GDP in this case). Finally, because the set of regressors do not vary with horizon h, the impulse response incorporates the average transitions of the economy between states. That is, there is no need to separately model how z changes over time (Auerbach and Gorodnichenko, 2012a). If fiscal shocks systematically affect the state of the economy, this effect will be absorbed into the estimated β's. In contrast, the system in (3.6.1) requires the explicit modelling of the the dynamics of z.

Following Auerbach and Gorodnichenko (2012b) and Ramey and Zubairy (2018), z is set equal to the seven-quarter moving average of output growth. The parameter γ in equation (3.6.4) governs the smoothness of the transition between states. Figure 3.9 plots the values of $F(z)$ for different values of γ along with the South African Reserve Bank (SARB) dated downswings. In the current application, γ is set equal to 4 so that the economy spends approximately 45% of the time in the recessionary regime, where the economy is assumed to be in recession when $F(z_t) > 0.6$. This calibration is consistent with the duration of recessions in South Africa over the sample according to SARB business cycle dates (49% of the time since 1970).

In estimating the set of regressions in (3.6.6) with output as dependent variable, the vector of control variables, x, contains four lags of the log of real per capita GDP, government spending, and total tax revenue. In addition, x contains lags of the shock variable to control for any serial correlation. The structural shocks identified in Section 3.4 are used as the shock variable. The estimation horizon is set equal to 12 quarters, i.e. $h = 12$ in (3.6.6) - the average duration of recession states over the sample.

Figures 3.10 and 3.11 show the output response under the different regimes following shocks to government spending and taxes respectively, with columns referencing the identification scheme employed to estimate the structural shocks used as input in estimating (3.6.6). Impulse responses are scaled as before. Table 3.6 presents present-value multipliers under the different states and identification schemes.

Figure 3.10: State dependent output response to a government spending shock

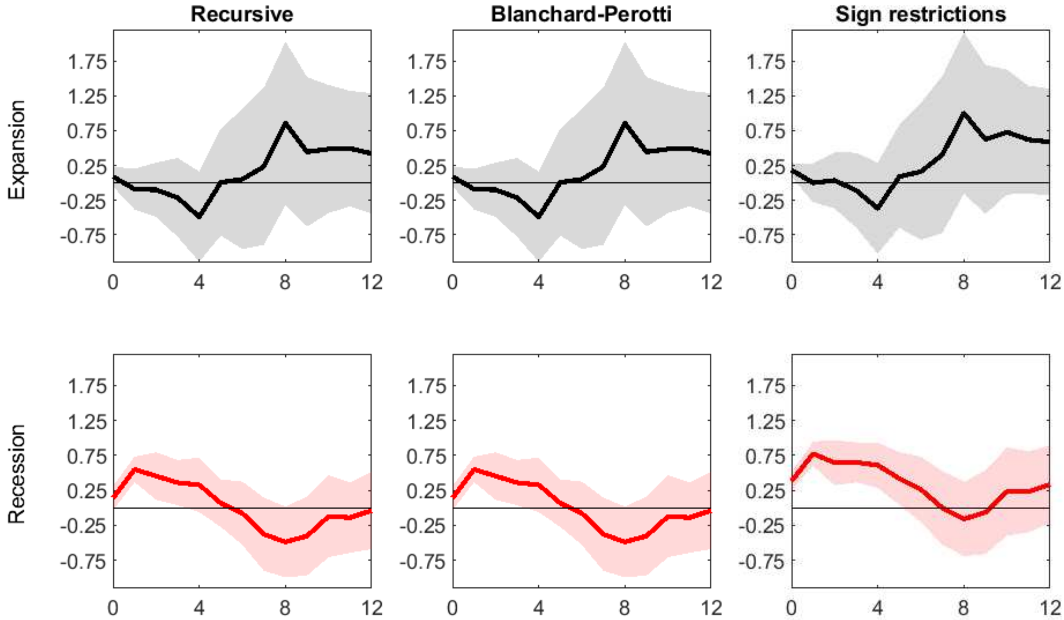
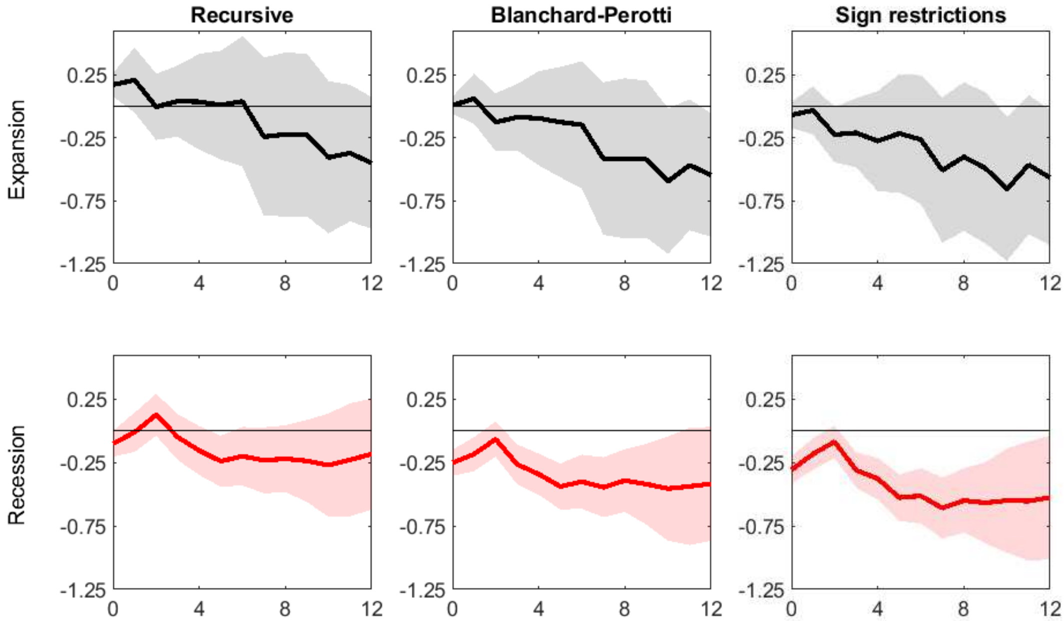


Figure 3.11: State dependent output response to a tax shock



Note: Columns refer to the shock processes embedded in equation (3.6.6). The figures show impulse responses to a R1 increase in the fiscal variable. Shaded areas represent 90% intervals.

From the impulse responses it is evident that there is a clear difference between the responses of output to a government spending shock in the different regimes, with a larger output response recorded under the recession regime than under the expansion regime. This is particularly true over the one-year horizon. This observation is borne out by the implied present-value multipliers in Table 3.6, where output multipliers are significantly larger under the recession regime no matter the identification approach employed. Additionally, while the confidence bands suggest that the output response is not statistically significant under the expansion regime, the output response under the recession regime is statistically different from zero, at least over the first four quarters following the shock to government spending.

The difference in output responses following a tax shock are less clear. However, the present value multipliers in Table 3.6 suggest that the negative output response following a tax shock is significantly larger under the recession regime than under the expansion regime. The calculation of the present value multipliers in Table 3.6 takes into account the difference in the cumulative response of taxes under the different regimes following the shock (see equation (3.4.1)). Tax revenues decline faster under the recessionary regime following the tax shock, resulting in the clear divergence in present-value output multipliers relative to the expansionary regime. As with the government spending shock, the output response to a tax shock is never significantly different from zero under the expansion regime. In contrast, the response is statistically significant under the recession regime across most of the impulse horizon, particularly under the BP and SR identification approaches.

Table 3.6: Present-value output multipliers under different regimes

	Q1	Q4	Q8	Q12
Government spending multiplier				
Recursive				
Linear	0.11	0.39	0.41	0.43
Expansion	0.09	-0.18	0.00	0.15
Recession	0.14	0.58	0.33	0.24
Blanchard-Perotti				
Linear	0.11	0.39	0.41	0.43
Expansion	0.09	-0.18	0.00	0.15
Recession	0.14	0.58	0.33	0.24
Sign restrictions				
Linear	0.33	0.79	0.87	0.95
Expansion	0.19	-0.04	0.18	0.36
Recession	0.38	0.89	0.74	0.74
Tax multiplier				
Recursive				
Linear	0.00	-0.06	-0.24	-0.46
Expansion	0.17	0.19	0.08	-0.11
Recession	-0.10	-0.07	-0.28	-0.43
Blanchard-Perotti				
Linear	-0.20	-0.69	-1.16	-1.76
Expansion	0.01	-0.08	-0.28	-0.59
Recession	-0.25	-0.48	-0.88	-1.24
Sign restrictions				
Linear	-0.29	-0.93	-1.63	-2.47
Expansion	-0.07	-0.30	-0.54	-0.88
Recession	-0.31	-0.56	-1.14	-1.65

Note: The linear model refers to results obtained from estimating the set of regressions in (3.6.5), i.e. using the full sample.

3.7 Conclusion

This chapter used a variety of identification approaches and model specifications to investigate the response of macroeconomic aggregates to fiscal policy innovations. Similar to results found in the literature, the estimated impulse responses and implied fiscal multipliers are sensitive to the identification approach employed.

It needs to be noted that the wide range of multipliers documented in the literature narrows significantly once methods for calculating multipliers are standardized. This requires calculating multipliers as the ratio of the cumulative macro variable response to the cumulative fiscal response (which more accurately represents theoretical multipliers), as opposed to the size of the effect on impact or the constant, non-cumulative rand value. It must be pointed out, however, that the cumulated multipliers are discounted at the mean interest rate for the sample, and that they are scaled by the ratio of the fiscal variable to the macro variable evaluated at the sample mean. These transformations introduce sample selection biases which need to be considered when drawing policy conclusions.

Keeping this caveat in mind, results show that government spending multipliers are generally positive, albeit smaller than one. An important exception is when the models are extended to control for the effects of monetary policy. While present value spending multipliers remain positive over short horizons, the long-term spending multiplier turns negative in models that account for the effects of monetary policy. Long-term (i.e. twenty-quarter) present-value government spending multipliers range from -0.24 to 1.06. Tax multipliers are found to be statistically significant and larger (in absolute terms) than spending multipliers, pointing to the significant effects of tax shocks on macroeconomic outcomes. Long-term present-value tax multipliers range from -0.15 to -4.28.

The private consumption and investment responses broadly mirror that of output in that tax shocks are significantly more distortionary than shocks to government spending. Importantly, while consumption reacts positively to government spending shocks over the short ruin, the response is short-lived. Present-value consumption multipliers range from -0.33 to 0.31 for government spending, and between -0.19 and -4.05 for taxes. Present-value investment multipliers range from -0.26 to 0.13 for government spending, and between -0.47 and -10.99 for taxes.

Finally, the possibility of state-dependent multipliers was investigated using local-projection methods. It is found that both government spending and tax multipliers are larger during periods of slack, with long-term present-value multipliers doubling in size during recessionary states.

A general observation is that the multipliers estimated in this chapter are somewhat smaller than those found in the literature, at least with respect to the developed world. As mentioned above, multipliers tend to be smaller in open, less developed economies. This could be due to a range of factors. On the spending side, possible factors include import leakages, corruption, and spending inefficiencies (i.e. inefficiencies in implementation of spending plans). Counteracting monetary policy is another factor that might result in lower spending multipliers, as reflected in the results discussed in Section 3.5.2. Similarly, the relatively large (negative) tax multipliers might be related to both behavioural and institutional factors. Behavioural factors relate to the ETI estimates in Chapter 2, while institutional factors could be reflective of problems in enforcement and/or collection and tax structure, The latter could include the availability of exemptions and deductions, and the opportunity for tax avoidance/evasion in the face of rising tax rates.

It should also be noted that all of the identification procedures employed in this chapter, and in the literature in general, imposes relatively strong priors on the results. The recursive and BP approaches imposes explicit restrictions on the contemporaneous relationships between variables, while the sign restrictions approach is subjective in that only those draws are kept which conform to the researcher's expectations. Even the popular event-study approach assumes that the correct instruments have been identified and that these are, in fact, orthogonal to output. These caveats should be considered when making policy recommendations based on estimated multipliers.

Having said that, the estimates in this chapter, combined with insights from Chapter 2 regarding the individual behavioural response to changing tax rates, suggest that should South African authorities need to embark on a fiscal consolidation drive, policies should be designed in favour of cutting government consumption expenditure as opposed to raising taxes. Unfortunately, this is the exact opposite approach to that followed by the South African government over recent years, with significant personal tax increases bearing the brunt of the responsibility for fiscal consolidation.

That being said, this chapter does not distinguish between the different effects of current government expenditure and public investment expenditure, and/or the effects of different tax measures (i.e. PIT versus CIT). While future research could investigate the differentiated impacts of the different spending and tax measures within the current reduced-form framework, the next chapter casts the problem in a structural model and investigates the differentiated impact of alternative policy instruments within a fully fleshed out dynamic structural model.

Chapter 4

A medium-sized, open-economy, fiscal DSGE model of South Africa

4.1 Introduction

Much of the research on fiscal multipliers has used identification methods and (reduced-form) modelling approaches similar to those employed in Chapter 3. While these models have been extended to include richer controls and innovative identification approaches in an effort to refine the analysis, a question that often arises is whether shocks identified in these reduced-form models, more often than not with minimal theoretical restrictions, capture the *true* structural shocks.

An alternative, more theoretically way to identify shocks to government spending and taxes is through estimated dynamic stochastic general equilibrium (DSGE) models. Given their theoretical consistency and inherently forward-looking nature, DSGE models present a useful tool for policy analysis, and fiscal policy analysis in particular. The rational expectations paradigm embedded in the DSGE framework imply that agents' beliefs about which fiscal instruments are used to finance public debt play a crucial role in the determination of the equilibrium as well as the dynamic response of endogenous variables, including output.

In light of these considerations, an open-economy DSGE model in the New Keynesian tradition, but with a more detailed fiscal block as in Coenen et al. (2013), is estimated in an attempt to improve our understating of the size (and direction) of the impact of fiscal policy shocks on macroeconomic outcomes in the South African context. Apart from the now standard set of nominal rigidities, the model contains several features that make it suitable for fiscal policy analysis, namely non-Ricardian (or rule-of-thumb) consumers, utility-enhancing government spending, and distortionary taxes.

Policy simulations based on the estimated model indicate that government spending and investment multipliers are generally positive, albeit smaller than one. Secondly, it is found that taxes are highly distortionary, with large negative multipliers for private consumption and investment. In contrast, the impact of tax shocks on output is ambiguous and depends on assumptions regarding the functional form of the different fiscal rules. Finally, an investigation into debt dynamics suggests that government consumption spending and, to a lesser extent, labour and consumption taxes are the most effective instruments for stabilising debt after a fiscal shock.

The rest of the chapter proceeds as follows: Section 4.2 provides a brief overview of the literature, while Section 4.3 provides details on the DSGE model. Section 4.4 provides details on the estimation procedure as well as estimation results. 4.5 presents various simulation results, including fiscal multiplier analysis, and Section 4.6 concludes with some final thoughts and ideas for further research.

4.2 Literature review

As mentioned before, while the international literature is filled with studies into the effects of fiscal policy on macroeconomic outcomes, no consensus has been reached on the size (or sign) of government spending multipliers.

In one of the earliest studies on the impact of fiscal policy decisions using structural general equilibrium models, Baxter and King (1993) showed that in a simple real business cycle (RBC) model extended to include lumpsum taxes, an increase in government spending results in a negative wealth effect for households due to the associated increase in the discounted future value of taxes. This negative wealth effect, in turn, induces a positive labour supply response and an associated decrease in private consumption and a fall in real wages. New Keynesian models (which add both real and nominal frictions to the RBC framework), display the same wealth-effect that induces a positive labour supply response and a fall in private consumption, although in this context real wages might increase as a result of increased demand for labour (Forni et al., 2009).

However, as mentioned in Chapter 3, these theoretical correlations did not appear to match up with evidence from applied research. In order to reconcile the theoretical predictions with results from the empirical literature, recent studies in the DSGE literature has recognised the heterogeneity in consumer behaviour apparent in the data and moved away from the restrictive assumption of the representative, infinitely-lived, rational agent. Mankiw (2000) argued that models that contain both Ricardian and non-Ricardian agents (that do not have access to financial markets and, as such, cannot save or borrow to augment consumption expenditure) is better suited for fiscal policy analysis. The seminal contribution by Galí et al. (2007) embedded rule-of-thumb (or non-Ricardian) agents in a standard monetary New Keynesian model. They found that the presence of these rule-of-thumb consumers, together with sticky prices and deficit financing, produces sizeable positive fiscal multipliers in the model economy.

Subsequent literature embedded this idea of rule-of-thumb consumers in the class of models of Smets and Wouters (2005, 2007) and Christiano et al. (2005). These models incorporate many of the features that have been shown to be useful in accounting for different aspects of the variation in macroeconomic aggregates, such as sticky prices, sticky wages, investment adjustment costs, habit persistence, etc. These richer models were shown to match the data reasonably well and could be used to generate estimates of the quantitative importance of rule-of-thumb consumers. Seminal examples of efforts in that direction can be found in Coenen and Straub (2005), Erceg et al. (2006), Rabanal and Lopez-Salido (2006) and Forni et al. (2009).

In contrast to Galí et al. (2007), Coenen and Straub (2005) found that little evidence that government spending shocks crowd in consumption, mainly because the estimated share of rule-of-thumb consumers is relatively low for the Eurozone - the estimated share of non-Ricardian households across their sample is significantly smaller than the mean of the prior which was set equal 0.5 on the basis of micro-based estimates obtained for the pre-1990 period in the US. In contrast, Erceg et al. (2006) found large, positive short-run fiscal multipliers associated with temporary increases in government spending. Similarly, Rabanal and Lopez-Salido (2006) found that private consumption increases after a government spending shock when either non-separability in consumption-hours, non-Ricardian behaviour, or both, are introduced in the model.

Most of the early literature focused on lump-sum taxes and aggregate government spending. Forni et al. (2009), among others, extended the framework of Christiano et al. (2005) and Galí et al. (2007) by including a detailed fiscal block. On the revenue side, the authors considered different distortionary tax rates, embedded in simple policy rules. On the expenditure side, they considered government consumption excluding compensation for public employees (or government purchases of goods and services) and modelled public employment separately in order to gauge the differential impact of the different types of spending. They found that shocks to government purchases of goods and services and public sector compensation have small and temporary effects on macroeconomic aggregates, while shocks to transfers have a slightly larger and more permanent effect. The effects are more significant on the revenue side, with cuts in labour and consumption taxes inducing sizeable consumption and output responses, while reductions in capital taxes have a positive effect on private investment and total output in the medium run.

This highlights the importance of studying the underlying mix of government spending and tax decisions rather than just aggregate quantities. Mountford and Uhlig (2009) found substantial multipliers for the US that are comparable to those of Blanchard and Perotti (2002), but emphasized that tax cuts are more effective in stimulating demand than increases in government spending as the private consumption response to government spending increases is insignificant. In a similar vein, Coenen et al. (2012) used a version of the European Central Bank's New Area-Wide Model extended to include a detailed specification of the fiscal sector and found that discretionary fiscal measures implemented during the GFC increased annualized quarterly real GDP growth by up to 1.6 percentage points. However, the authors noted that a detailed modelling of the fiscal sector and the incorporation of several fiscal time series were pivotal for the result. Carvalho and Valli (2011) further distinguished between private and public capital accumulation and provides a mechanism through which public capital augments factor productivity in the private sector. This provides an additional avenue through which fiscal policy decisions can impact on real macroeconomic outcomes.

An alternative approach that seeks to mimic the positive wage and consumption responses often found in the empirical literature entails the introduction of a different habit formation process on the part of consumers. Ravn et al. (2010) developed a model of deep habits, which manages to produce positive consumption effects following a government spending impulse.[56] Christoffel et al. (2011) introduced a specific form of habit formation in the composite of consumption and leisure (as in Jaccard, 2010) in order to study their model's ability to generate a realistic bond premium, but at the same time find significant fiscal multipliers.

A further aspect of the policy response to the GFC that received little attention initially but has gained prominence recently is the fact that monetary and fiscal policy reacted *jointly* in an effort to stimulate demand. The interaction between monetary and fiscal policy is particularly important in an environment where governments the world over contemplate when and how to normalise policy. This interaction has important implications for the size of the fiscal multiplier. Davig and Leeper (2011) estimated Markov-switching policy rules for the US and found that monetary and fiscal policies fluctuate between active and passive states and that shocks to government spending induces positive consumption responses under certain policy regimes. In a follow-up paper, Leeper et al. (2015) found different sized multipliers for the US under different monetary-fiscal policy regimes. While output multipliers are comparable across regimes over the short-run, in the long run multipliers are much larger under the passive monetary/active fiscal policy regime than under active monetary/passive fiscal policy regime. Using a time varying parameter vector autoregression (TVP-VAR), Jooste et al. (2013) found fiscal multipliers for South Africa that differ across time and between expansions and recessions. In fact, a common finding in the literature is that fiscal policy appears to be more effective during periods of economic downturn than during expansions (see Auerbach and Gorodnichenko, 2012c; Baum et al., 2012; Owyang et al., 2013; Auerbach and Gorodnichenko, 2014; Canzoneri et al., 2015,

[56] Deep habits imply that households form habits over sub-categories of consumption goods, such as cars and clothing, as opposed to aggregate consumption.

among others).

Other studies have also investigated the impact of fiscal decisions when monetary policy is at (or close to) the zero nominal interest rate bound. Hall (2009) found that in an economy with an output multiplier of just under one in normal times, the multiplier can rise to 1.7 at a zero nominal interest rate, while Christiano et al. (2011) obtained an even stronger effect. Using a two-state Markov-switching framework, Eggertsson (2011) found that multipliers can be up to five times larger at the zero lower bound.

Several extensions have sought to enrich the basic model specifications in order to more closely resemble actual economies. One such extension is the inclusion of a mechanism for fiscal foresight on the model economy. According to Ramey (2011b) and Leeper et al. (2012), models that do not explicitly account for foresight is misspecified and biased responses. As shown in Jooste and Naraidoo (2017), fiscal foresight eliminates the results of Galí et al. (2007) in that a large share of rule-of-thumb consumers is not enough to generate positive co-movement between government spending and consumption. However, under certain calibrations, the inclusion of sticky wages still generates positive consumption responses and produces sizeable output multipliers.

The greater proportion of the literature on fiscal multipliers focus on closed economies in the vein of Galí et al. (2007). While some studies have investigated the impact of fiscal policy decisions within the context of an open economy (see Erceg et al., 2006; Cavallo, 2007; Ratto et al., 2007; Levine et al., 2009; Horvath and Marsal, 2014; Varthalitis, 2019 for examples), this is much less prevalent. This aspect is particularly important in the context of the South Africa economy and given the assertion in the literature that fiscal multipliers are generally smaller in an open economy setting.

Finally, despite the international interest in estimating the impact of fiscal shocks on macroeconomic outcomes, very little work has been done in the South African context. A notable exception is Jooste et al. (2013) who investigated the impact of fiscal policy shocks using three models: a medium-scale, closed-economy DSGE model, a (open-economy) structural vector error correction model (SVECM), and a time varying parameter vector autoregression (TVP-VAR). The use of these non-standard models allows the authors to answer some of the important questions raised in the field pertaining to the weaknesses of standard VARs (mentioned above). The authors found that increases in government expenditure have a positive effect on GDP in the short run (albeit less than unity in some instances), but that the impact becomes negligible in the long run. Similar results hold for changes to tax policy.

This chapter adds to the burgeoning fiscal DSGE literature by extending the baseline closed-economy model to an open economy setting, while at the same time including a more detailed fiscal sector and estimating key parameters.

4.3 The Model

The small open economy model structure closely follows that of Adolfson et al. (2007) and Christoffel et al. (2008), while incorporating a more active role for fiscal policy along the lines of Coenen et al. (2013).[57]

The basic open economy structure is relatively standard: Households consume both domestic and imported consumer goods, while optimizing agents can invest in domestic and foreign bonds. The optimizing households rent capital to firms and decide how much to invest each period, with changes to the rate of investment, as well as changes to the rate of capital utilisation, subject to adjustment costs. Each household supplies a differentiated labour service to firms, allowing them to set their wage in a Calvo (1983) manner.

[57] See Steinbach (2014) for an application of the Adolfson et al. (2007) model to South Africa.

The model contains three types of firms: domestic producers, importers and exporters. Domestic firms employ labour and capital in production. A differentiated good is produced by each type of firm. Prices are set following Calvo's (1983) model, but with a variation that allows for the indexation to past inflation (following Rabanal and Lopez-Salido (2006)).

Finally, monetary policy follows a standard Taylor-type rule, while the foreign economy is assumed to be exogenous.

This basic specification is extended along the lines of Coenen et al. (2013) to include a more active role for fiscal policy. The specification of the fiscal sector balances the need for a high degree of detail, which is essential for analysing the quantitative effects of fiscal policy innovations, and tractability, which allows for the identification of the relevant transmission mechanisms. Specifically, the model includes (i) non-Ricardian (or rule-of-thumb) consumers to facilitate a direct transmission mechanism for government transfers, (ii) government consumption that enters the households' utility function in a non-separable way, (iii) public capital which can either be a complement or substitute for private capital, (iv) time-varying distortionary taxes, and (v) a set of fiscal rules governing the endogenous response of fiscal variables.

4.3.1 Households

There is a continuum of households $h \in [0, 1]$. They derive utility from consuming a basket of domestic consumption goods, both private and public, while they exhibit disutility in supplying labour services.

Following Coenen and Straub (2005), Galí et al. (2007), Jooste et al. (2013), and Coenen et al. (2013), among others, the household sector is divided into two distinct groups. A share $i \in (\omega, 1]$ of households - referred to as Ricardian households - invest, accumulate capital and have access to both foreign and domestic financial markets, and display the standard optimizing behaviour. The remaining share $j \in [0, \omega]$ of households - referred to as non-Ricardian households - do not trade in assets and simply consume their after-tax disposable income. Importantly, Ricardian households can smooth consumption intertemporally in response to shocks, whereas non-Ricardian simply consume their after-tax disposable income (Coenen et al., 2013).

Furthermore, it is assumed that valuable government consumption enters the households' utility function in a non-separable way. This feature has two important implications. First, under this specification, shocks to government consumption affect optimal private consumption decisions directly. This stands in contrast to the indirect wealth effect associated with separable government consumption. Second, the feature implies that it is theoretically possible to generate co-movements between private and government consumption, conditional on the estimated degree of complementarity.

Formally, aggregate consumption $\tilde{C}_{h,t}$ of household h is defined as a constant elasticity of substitution (CES) aggregate

$$\tilde{C}_{h,t} = \left(\alpha_G^{\frac{1}{\nu_G}} \left(C_{h,t} \right)^{\frac{\nu_G - 1}{\nu_G}} + (1 - \alpha_G)^{\frac{1}{\nu_G}} \left(G_t \right)^{\frac{\nu_G - 1}{\nu_G}} \right)^{\frac{\nu_G}{\nu_G - 1}} \tag{4.3.1}$$

where $C_{h,t}$ denotes the household's consumption of private goods and G_t measures government consumption. α_G is a share parameter and ν_G measures the elasticity of substitution between private consumption and government consumption, with $\nu_G > 0$. In particular, $\nu_G \to 0$ implies that private and public consumption are perfect complements, $\nu_G \to \infty$ results in perfect substitutability, and the Cobb-Douglas case is obtained when $\nu_G \to 1$.

Ricardian households

Lifetime utility of the i-th Ricardian household is a separable function in (aggregate) consumption and labour given by:

$$E_t \sum_{k=0}^{\infty} \beta^k \left[\varepsilon_{t+k}^c \ln \left(\tilde{C}_{i,t+k} - \kappa \tilde{C}_{i,t+k-1} \right) - \varepsilon_{t+k}^n \frac{\left(N_{i,t+k}\right)^{1+\sigma_L}}{1+\sigma_L} \right] \tag{4.3.2}$$

where β denotes the discount factor, σ_L is the inverse of the Frisch elasticity of labour supply, and κ measures the degree of external habit formation. ε_t^c is the consumption preference shock, while ε_t^n represents a labour supply shock. These exogenous processes are assumed to evolve according to the following AR(1) specifications:

$$\begin{aligned} \hat{\varepsilon}_t^c &= \rho_{\varepsilon_c} \hat{\varepsilon}_{t-1}^c + \epsilon_t^c \qquad && \epsilon_t^c \sim \mathcal{N}(0, \sigma_c) \\ \hat{\varepsilon}_t^n &= \rho_{\varepsilon_n} \hat{\varepsilon}_{t-1}^n + \epsilon_t^n \qquad && \epsilon_t^n \sim \mathcal{N}(0, \sigma_n) \end{aligned}$$

where $E\left(\hat{\varepsilon}_t^i\right) = 1$ and $\hat{\varepsilon}_t^i = \left(\varepsilon_t^i - 1\right)/1$ for $i \in \{c, n\}$. Throughout the paper, a variable with a hat denotes a log-linearised variable, i.e. $\hat{X}_t = \frac{X_t - X}{X}$.

Budget constraint

The representative Ricardian household optimizes the utility function in equation (4.3.2) subject to the following budget constraint:

$$\begin{aligned} (1+\tau_t^c) P_{C,t} C_{i,t} + P_{I,t} I_{i,t} + \frac{B_{i,t+1}}{\varepsilon_t^{RP} R_t} + \frac{S_t B_{i,t+1}^*}{\left[1 - \Gamma_{B^*}\left(s_{B^*,t+1}; \varepsilon_t^{RP^*}\right)\right] R_t^*} \\ = (1-\tau_t^w) W_{i,t} N_{i,t} + (1-\tau_t^k)\left[R_{K,t} u_{i,t} - \Gamma_u(u_{i,t}) P_{I,t}\right] K_{i,t} + \tau_t^k \delta_t P_{I,t} K_{i,t} \\ + D_{i,t} + TR_{i,t} + B_{i,t} + S_t B_{i,t}^* + \Xi_{i,t}^B + \Xi_{i,t}^{B^*} \end{aligned} \tag{4.3.3}$$

where $P_{C,t}$ and $P_{I,t}$ are the unit prices of the private consumption and investment good, respectively. $(1-\tau_t^w) W_{i,t} N_{i,t}$ is net labour income, $(1-\tau_t^k) R_{K,t} u_t K_{i,t}$ is net nominal income from renting capital services $K_{i,t}^s = K_{i,t} u_t$ to firms at the rate $R_{K,t}$, and $D_{i,t}$ are profits distributed by firms to Ricardians (by assumption the only owners of firms). R_t and R_t^* denote the respective risk-free returns on domestic and foreign government bonds. Foreign government bonds are denominated in foreign currency and, therefore, are converted to domestic currency units using the nominal exchange rate S_t (expressed in terms of units of domestic currency per unit of foreign currency).

The fiscal authority finances its expenditures by issuing one period nominal bonds $B_{i,t}$ and by levying taxes on labour income (τ_t^w), capital income (τ_t^k) and consumption (τ_t^c). As in Coenen et al. (2013), it is assumed that the utilisation cost of capital and capital depreciation, $\delta_t P_{I,t} K_{i,t}$, is exempted from taxation.

The expenditure side features the amount of government bonds (both foreign and domestic) that Ricardian households carry over from the previous period, discounted by the nominal interest rate. However, the effective return on risk-free domestic bonds depends on a financial intermediation premium, represented by the exogenous "risk premium" shock ε_t^{RP}, which drives a wedge between the policy interest rate and the return required by the household. Similarly, following Christoffel et al. (2008), the household encounters an external financial intermediation premium $\Gamma_{B^*}\left(B^*_{t+1};\varepsilon^{RP^*}_t\right)$ when taking a position in the international bond market. This premium depends on the economy-wide holdings of foreign bonds expressed in domestic currency units relative to domestic nominal output, $s_{B^*,t+1} = S_t B^*_{t+1}/P_{Y,t}Y_t$, and takes the form:

$$\Gamma_{B^*}\left(s_{B^*,t+1};\varepsilon^{RP^*}_t\right) = \gamma_{B^*}\left(\left(\varepsilon^{RP^*}_t\right)^{\frac{1}{\gamma_{B^*}}}\exp\left(\frac{S_t B^*_{t+1}}{P_{Y,t}Y_t}\right) - 1\right) \tag{4.3.4}$$

with $\gamma_{B^*} > 0$. That is, if the domestic economy is a net debtor, households have to pay a higher external intermediation premium when investing in foreign capital markets. The shock $\varepsilon^{RP^*}_t$ represents the exogenous component of the external intermediation premium and is referred to as the external risk premium shock. The incurred intermediation premia are rebated in the form of lump-sum payments, $\Xi^B_{i,t}$ and $\Xi^{B^*}_{i,t}$.

Finally, adjustment costs are introduced on the households choice of capacity utilisation $u_{i,t}$. This cost is incurred if the level of capital utilisation deviates from its steady state value of one. The cost is described by an increasing convex function $\Gamma_u(u_{i,t})$, with $\Gamma_u(1) = 0$. Hence $\Gamma_u(u_{i,t})P_t K_{i,t}$ denotes the cost associated with the utilisation level $u_{i,t}$.

The adjustment cost takes the following functional form:

$$\Gamma_u(u_{i,t}) = \gamma_{u,1}(u_{i,t} - 1) + \frac{\gamma_{u,2}}{2}(u_{i,t} - 1)^2 \tag{4.3.5}$$

with $\gamma_{u,1}, \gamma_{u,2} > 0$.

Capital and investment

The physical capital stock owned by household i evolves according to the following capital accumulation equation:

$$K_{i,t+1} = (1-\delta)K_{i,t} + \varepsilon^i_t\left(1 - \Gamma_I\left(I_{i,t}/I_{i,t-1}\right)\right)I_{i,t} \tag{4.3.6}$$

where δ is the depreciation rate, $\Gamma_I\left(I_{i,t}/I_{i,t-1}\right)$ represents an adjustment cost function, and ε^i_t is an investment specific technology shock. This shock follows the AR(1) process

$$\hat{\varepsilon}^i_t = \rho_c \hat{\varepsilon}^i_{t-1} + \epsilon^i_t \qquad \epsilon^i_t \sim \mathcal{N}(0, \sigma_i)$$

with $E\left[\varepsilon^i_t\right] = 1$ and $\hat{\varepsilon}^i_t = \left(\varepsilon^i_t - 1\right)/1$.

Following Christoffel et al. (2008), the investment adjustment cost function, formulated as a function of the rate of change in gross private investment, takes the following form:

$$\Gamma_I\left(I_{i,t}/I_{i,t-1}\right) = \frac{\gamma_I}{2}\left(\frac{I_{i,t}}{I_{i,t-1}} - g_z\right)^2 \tag{4.3.7}$$

with $\gamma_I > 0$ and where g_z denotes the economy's trend growth rate in the non-stochastic steady state.

First order conditions

Taking all fiscal variables and prices, including wages, as given and defining $\Lambda_{i,t}/P_t$ and $\Lambda_{i,t}Q_{i,t}$ as the Lagrange multipliers associated with the budget constraint (4.3.3) and the capital accumulation equation (4.3.6) respectively, optimisation of the household's utility function yields the following first-order conditions with respect to $\left\{C_{i,t}, I_{i,t}, K_{i,t+1}, u_{i,t}, B_{i,t+1}, B^*_{i,t+1}\right\}$:

Consumption, $C_{i,t}$

$$\Lambda_{i,t} = \alpha_G^{\frac{1}{\nu_G}} \varepsilon_t^c \frac{\left(\tilde{C}_{i,t} - \kappa \tilde{C}_{i,t-1}\right)^{-1}}{1+\tau_t^c} \left(\frac{\tilde{C}_{i,t}}{C_{i,t}}\right)^{\frac{1}{\nu_G}} \tag{4.3.8}$$

Investment, $I_{i,t}$

$$\begin{aligned} \frac{P_{I,t}}{P_{C,t}} = Q_{i,t}\varepsilon_t^i &\left[1 - \Gamma_I\left(\frac{I_{i,t}}{I_{i,t-1}}\right) - \Gamma_I'\left(\frac{I_{i,t}}{I_{i,t-1}}\right)\frac{I_{i,t}}{I_{i,t-1}}\right] \\ &+\beta E_t\left[\frac{\Lambda_{i,t+1}}{\Lambda_{i,t}} Q_{i,t+1}\varepsilon_{t+1}^i \Gamma_I'\left(\frac{I_{i,t+1}}{I_{i,t}}\right)\frac{I_{i,t+1}^2}{I_{i,t}^2}\right] \end{aligned} \tag{4.3.9}$$

Capital stock, k_{t+1}

$$\begin{aligned} Q_{i,t} = \beta E_t \Bigg[\frac{\Lambda_{i,t+1}}{\Lambda_{i,t}} \Bigg(&(1-\delta)Q_{i,t+1} + (1-\tau_{t+1}^k)\frac{R_{K,t+1}}{P_{C,t+1}}u_{i,t+1} \\ &+ \left(\tau_{t+1}^k \delta - (1-\tau_{t+1}^k)\Gamma_u(u_{i,t+1})\right)\frac{P_{I,t+1}}{P_{C,t+1}}\Bigg)\Bigg] \end{aligned} \tag{4.3.10}$$

Capital utilisation, u_t

$$R_{K,t} = \Gamma_u'(u_{i,t})P_{I,t} \tag{4.3.11}$$

Domestic bond holdings, $B_{i,t+1}$

$$\beta \varepsilon_t^{RP} R_t E_t\left[\frac{\Lambda_{i,t+1}}{\Lambda_{i,t}}\frac{P_{C,t}}{P_{C,t+1}}\right] = 1 \tag{4.3.12}$$

Foreign bond holdings, $B^*_{i,t+1}$

$$\beta\left(1 - \Gamma_{B^*}\left(s_{B^*,t+1}; \varepsilon_t^{RP^*}\right)\right) R_t^* E_t\left[\frac{\Lambda_{i,t+1}}{\Lambda_{i,t}}\frac{P_{C,t}}{P_{C,t+1}}\frac{S_{t+1}}{S_t}\right] = 1 \tag{4.3.13}$$

Here, $\Lambda_{i,t}$ represents the shadow price of a unit of consumption good, i.e. the marginal utility of consumption out of income. Similarly, $Q_{i,t}$ measures the shadow price of a unit of investment good, i.e. Tobin's Q.[58]

In equilibrium, with all households choosing identical allocations, the combination of (4.3.12) and (4.3.13) yields the risk-adjusted uncovered interest parity (UIP) condition, reflecting the assumption that the return on foreign bonds is subject to an external financial intermediation premium.

[58] As noted in Christoffel et al. (2008), the domestic risk premium shock, ε_t^{RP} affects investment via Tobin's Q and helps to explain the co-movement of consumption and investment observed in the data. In contrast, the consumption preference shock, ε_t^c, moves consumption and investment in opposite directions.

Non-Ricardian households

Non-Ricardian households face the same utility function as Ricardian households. However, they do not display the standard optimizing behaviour, cannot invest in physical capital, and do not have access to financial markets. As a result, each non-Ricardian household $j \in [0, \omega]$ simply consumes its disposable income, comprising after-tax disposable income and government transfers, in each period. The period-by-period budget constraint is:

$$(1 + \tau_t^c) P_{C,t} C_{j,t} = (1 - \tau_t^w) W_{j,t} N_{j,t} + TR_{j,t} \tag{4.3.14}$$

Following Coenen et al. (2013), a possibly uneven distribution of government transfers amongst Ricardian and non-Ricardian households is allowed according to:

$$\bar{\omega} \left(TR_{i,t} / TR_i - 1 \right) = (1 - \bar{\omega}) \left(TR_{j,t} / TR_j - 1 \right)$$

Labour market and wages

Each household h supplies its differentiated labour services $N_{h,t}$ in monopolistically competitive markets. It is assumed that the labour force of all households is uniformly distributed among the differentiated firms, and that employers cannot distinguish between different labour types. Furthermore, following Adolfson et al. (2007), Christoffel et al. (2008), and Coenen et al. (2013), among others, wage adjustments are sluggish due to the presence of staggered wage contracts, modelled as a Calvo (1983) process.

Note that, by assumption, non-Ricardians do not display intertemporal optimizing behaviour. Following Erceg et al. (2006) and Forni et al. (2009), it is assumed that the non-Ricardian wage rate equals the average of the Ricardians. Since all households face the same labour demand schedule in the private sector, this implies that both the wage rate and hours worked will be equal for every agent in the economy.

Following Calvo (1983), the representative Ricardian household i optimally resets its nominal wage contract $W_{i,t}$ in a given period t with probability $1 - \theta_w$. All households that are allowed to reset their wage contracts choose the same wage rate, $\widetilde{W}_t = \widetilde{W}_{i,t}$. Those households that do not reset their wage adjust their wage contracts to reflect developments in underlying productivity and inflation:

$$W_{i,t} = g_{z,t} \Pi_{C,t}^{\dagger} W_{i,t-1} \tag{4.3.15}$$

where $g_{z,t}$ represents the underlying rate of productivity growth and $\Pi_{C,t}^{\dagger} = (\pi_{C,t-1})^{\chi_W} (\bar{\pi}_{C,t})^{1-\chi_W}$ is a geometric average of past consumer price inflation $\pi_{C,t-1} = P_{C,t-1}/P_{C,t-2}$ and the monetary authority's possibly time-varying inflation objective, $\bar{\pi}_{C,t}$. The indexation parameter χ_W determines weight attached to past inflation.

The representative Ricardian household that reset its wage contract in period t maximises lifetime utility (given by (4.3.2)) subject to the budget constraint (4.3.3), the demand for its differentiated labour services, and the wage-indexation scheme (4.3.15).

Using the fact that in equilibrium all households choose the same optimal reset wage $\widetilde{W}_t$, the optimisation results in the following first-order condition characterising the representative Ricardian household's optimal wage-setting decision:

$$E_t\left[\sum_{k=0}^{\infty}(\theta_W\beta)^k\left(\Lambda_{t+k}(1-\tau^w_{t+k})g_{z;t,t+k}\frac{\Pi^{\dagger}_{C;t,t+k}}{\Pi_{C;t,t+k}}\frac{\widetilde{W}_t}{P_{C,t}}-\phi^W_{t+k}\varepsilon^n_{t+k}\left(N_{i,t+k}\right)^{\sigma_L}\right)N_{i,t+k}\right]=0 \tag{4.3.16}$$

where Λ_{t+k} denotes the marginal utility out of income, $g_{z;t,t+k}=\prod_{s=1}^{k}g_{z,t+s}$, $\Pi^{\dagger}_{C;t,t+k}=\prod_{s=1}^{k}\left(\pi_{C,t-1}\right)^{\chi_W}\left(\bar{\pi}_{C,t}\right)^{1-\chi_W}$, and $\Pi_{C;t,t+k}=\prod_{s=1}^{k}\pi_{C,t+s-1}$.

As noted in Christoffel et al. (2008), this expression implies that in those labour markets in which wage contracts are re-optimised, optimal wage rates are set so as to equate the households' discounted sum of expected after-tax marginal revenues, expressed in consumption-based utility terms, Λ_{t+k}, to the discounted sum of expected marginal cost, expressed in terms of marginal disutility of labour, $\Delta_{i,t+k}=-N^{\sigma_L}_{i,t+k}$. In the absence of wage staggering $\xi_w=0$, ϕ^W_t represents the time-varying markup of the real after-tax wage over the households' marginal rate of substitution between consumption and leisure,

$$(1-\tau^w_t)\frac{\tilde{W}_t}{P_{C,t}}=-\phi^W_t\varepsilon^n_t\frac{\Delta_t}{\Lambda_t} \tag{4.3.17}$$

reflecting the existence of monopoly power on the part of the households.[59]

Aggregate wage dynamics

As mentioned above, it is assumed that the non-Ricardian wage rate simply equals the average of the Ricardians.[60] Since all households face the same labour demand schedule in the private sector, this assumption implies that both the wage rate and hours worked will be equal for every agent in the economy. In other words, the common economy-wide wage rate, $W_{i,t}=W_{j,t}(=W_{h,t})=W_t$, and identical labour demand curves imply that Ricardian and non-Ricardian households supply the same amount of labour, i.e. $N_{i,t}=N_{j,t}(=N_{h,t})=N_t$.

Furthermore, with the continuum of households setting wage contracts on the basis of equation (4.3.15) and equation (4.3.16), the aggregate wage index W_t evolves according to:

$$W_t=\left(\theta_W\left(g_{z,t}\Pi^{\dagger}_{C,t}W_{t-1}\right)^{\frac{1}{1-\phi^W_t}}+(1-\theta_W)\left(\widetilde{W}_t\right)^{\frac{1}{1-\phi^W_t}}\right)^{1-\phi^W_t} \tag{4.3.18}$$

4.3.2 Production

The structure closely follows that of Christoffel et al. (2008) and Coenen et al. (2013). There are two types of monopolistically competitive intermediate-good firms: A continuum of domestic intermediate-good firms indexed by $f\in[0,1]$ producing differentiated goods that are sold both domestically and abroad, and a continuum of foreign intermediate-good firms indexed by $f^*\in$

[59]Using the fact that, in equilibrium, the marginal disutility is equal across households, i.e. $\Delta_{i,t}=\Delta_t$.

[60]This is a simplifying assumption. Non-Ricardians appear in the model because of credit market imperfections (i.e. they cannot borrow and save to smooth their consumption). This also implies that these individuals might be lower-income workers with no collateral. As such, their wage rates might be different, and indeed lower, than the wage rates of Ricardians. Several authors, including Forni et al. (2009) (using a similar model set-up to the one discussed here), check a more general version of the labour market, able to recognize a role for non-Ricardian preferences in labour choices even if they cannot optimize intertemporally. The authors find no substantial difference between the results of the simple specification and the more complex approach, and find that it is indeed the assumed share of non-Ricardian households that is important from a model dynamic perspective. As such, the assumption of equal wage rates is maintained in the subsequent analysis.

[0, 1] producing goods for the domestic market. Additionally, there is a set of four representative domestic final-good firms which combine the differentiated domestic and foreign intermediate goods into four distinct non-tradeable goods, namely a private consumption good, a public consumption good, a private investment good, and a public investment good.

Domestic intermediate-good firms

Production

The intermediate good producing firms operate in a monopolistically competitive environment and produce differentiated goods according to the following production technology:

$$Y_{f,t} = \varepsilon_t \left(\tilde{K}_{f,t}\right)^{\alpha} \left(z_t N_{f,t}\right)^{1-\alpha} - z_t \psi \tag{4.3.19}$$

where z_t is a permanent technology shock, ε_t is a temporary (covariance stationary) technology shock, $\tilde{K}_{f,t}$ is physical capital services, and $N_{f,t}$ denotes the homogeneous labour input hired by firm f.

$$N_{f,t} = \left(\int_0^1 \left(N_{f,t}^h\right)^{\frac{1}{\phi_t^W}} dh\right)^{\phi_t^W} \tag{4.3.20}$$

As discussed above, the parameter ϕ_t^W has a natural interpretation as a markup in the household-specific labour market.

The introduction of a fixed cost, $z_t\psi$, ensures zero steady-state firm profits. It is assumed that the growth in fixed cost is equal to the steady-state growth rate in underlying productivity. [61]

As before, the stationary technology shock has the following presentation:

$$\hat{\varepsilon}_t = \rho_\varepsilon \hat{\varepsilon}_{t-1} + \epsilon_t^\varepsilon \qquad \epsilon_t^\varepsilon \sim \mathcal{N}(0, \sigma_\varepsilon) \tag{4.3.21}$$

where $E(\varepsilon_t) = 1$ and $\hat{\varepsilon}_t = (\varepsilon_t - 1)/1$.

The process for the permanent technology shock, z_t, in equation (4.3.19) is given by:

$$\frac{z_t}{z_{t-1}} = g_{z,t} = \left(1 - \rho_{g_z}\right) g_z + \rho_{g_z} g_{z,t-1} + \epsilon_{g_z,t} \qquad \epsilon_{g_z,t} \sim \mathcal{N}(0, \sigma_{g_z}) \tag{4.3.22}$$

where g_z is the steady-state growth rate of technology. Fixed costs are scaled by z_t to guarantee that share of fixed costs with respect to output does not vanish as output grows.

Following Coenen et al. (2013), the production function (4.3.19) is augmented with public capital in the presence of a well-specified government sector (which invests in public capital). Physical capital used in production is a CES aggregate of private capital services $K_{f,t}^s$ and the public capital stock $K_{G,t}$:

$$\tilde{K}_{f,t} = \left(\alpha_K^{\frac{1}{\nu_K}} \left(K_{f,t}^s\right)^{\frac{\nu_K - 1}{\nu_K}} + \left(1 - \alpha_K\right)^{\frac{1}{\nu_K}} \left(K_{G,t}\right)^{\frac{\nu_K - 1}{\nu_K}}\right)^{\frac{\nu_K}{\nu_K - 1}} \tag{4.3.23}$$

[61]The parameter ψ is calibrated to ensure zero profits in steady state. The zero profit condition guarantees that, in equilibrium, there is no incentive for other firms to enter the market.

where α_K is a share parameter, and, analogous to the CES consumption aggregate, the parameter $\nu_K > 0$ governs the elasticity of substitution between private capital services and the public capital stock. $\nu_K \to 0$ implies private capital services and public capital are perfect complements, $\nu_K \to \infty$ implies they are perfect substitutes, and $\nu_K \to 1$ yields the Cobb-Douglas case. The law of motion for public capital is analogous to that for private capital formation (equation (4.3.6)):

$$K_{G,t+1} = (1-\delta_G)K_{G,t} + \varepsilon_t^i \left(1 - \Gamma_G\left(I_{G,t}/I_{G,t-1}\right)\right) I_{G,t} \tag{4.3.24}$$

where Γ_G takes the same form as in equation (4.3.7).

Importantly, each intermediate-good firm f has access to the same public capital stock. Additionally, the stock of public capital is assumed to grow at the same speed as private capital services along the balanced growth path of the model. Public capital augments private production at no direct cost for the firm and can in this case be interpreted as an externality to the private productive sector. Financing of public capital is not factored into the cost accounting of firms as it takes place through the general tax system. Finally, note that K_t^s might differ from the physical private capital stock in the presence of variable capital utilisation, u_t, i.e. $K_t^s = u_t K_t$.

The intermediate good firm rents private capital services at a gross nominal rate $R_{K,t}$ and compensates the homogeneous labour service at the nominal wage rate W_t. Defining $MC_{f,t}$ as the Lagrange multiplier associated with the technology constraint (4.3.19), i.e. nominal marginal cost, the firm's cost minimization problem is as follows:

$$\min_{K_{f,t}^s, N_{f,t}} W_t N_{f,t} + R_{K,t} K_{f,t}^s + MC_{f,t}\left[Y_{f,t} - \varepsilon_t\left(\tilde{K}_{f,t}\right)^{\alpha}(z_t N_{f,t})^{1-\alpha} + z_t\psi\right] \tag{4.3.25}$$

Optimisation w.r.t $K_{f,t}^s$ and $N_{f,t}$ yields the following first order conditions:

$$R_{K,t} = \alpha \frac{Y_{f,t} + z_t\psi}{K_{f,t}^s}\left[1 + \left(\frac{1-\alpha_K}{\alpha_K}\right)^{\frac{1}{\nu_K}}\left(\frac{K_{G,t}}{K_{f,t}^s}\right)^{\frac{\nu_K - 1}{\nu_K}}\right]^{-1} MC_{f,t} \tag{4.3.26}$$

and

$$W_t = (1-\alpha)\frac{Y_{f,t} + z_t\psi}{N_{f,t}} MC_{f,t} \tag{4.3.27}$$

or, more compactly,

$$\frac{R_{K,t}}{W_t} = \frac{\alpha}{1-\alpha}\frac{N_{f,t}}{K_{f,t}^s}\left[1 + \left(\frac{1-\alpha_K}{\alpha_K}\right)^{\frac{1}{\nu_K}}\left(\frac{K_{G,t}}{K_{f,t}^s}\right)^{\frac{\nu_K - 1}{\nu_K}}\right]^{-1} \tag{4.3.28}$$

Since all firms f face the same input prices and since they all have access to the same production technology, nominal marginal costs $MC_{f,t}$ are identical across firms, that is, $MC_{f,t} = MC_t$ with

$$MC_t = \frac{1}{\varepsilon_t z_t^{1-\alpha}\alpha^{\alpha}(1-\alpha)^{1-\alpha}}\left(R_{K,t}\right)^{\alpha}\left(W_t\right)^{1-\alpha}\left(\frac{K_t^s}{\tilde{K}_t}\right)^{\alpha}\left[1 + \left(\frac{1-\alpha_K}{\alpha_K}\right)^{\frac{1}{\nu_K}}\left(\frac{K_{G,t}}{K_t^s}\right)^{\frac{\nu_K - 1}{\nu_K}}\right]^{\alpha} \tag{4.3.29}$$

As discussed above, the nominal wage contract $W_{h,t}$ for the differentiated labour services of household h is set in monopolistically competitive markets. This implies that firm f takes $W_{h,t}$ as given and chooses the optimal labour input by minimising the total wage-related labour cost, $\int_0^1 W_{h,t} N_{f,t}^h dh$, subject to the aggregation constraint (4.3.20).

As a result, the demand for labour variety h is a function of the ratio of household-specific wage rate $W_{h,t}$ to the aggregate wage index W_t:

$$N_{f,t}^h = \left(\frac{W_{h,t}}{W_t}\right)^{-\frac{\phi_t^W}{\phi_t^W - 1}} N_{f,t} \tag{4.3.30}$$

with $\phi_t^W / (\phi_t^W - 1)$ representing the wage elasticity of labour demand.

The wage index W_t can be obtained by substituting the labour index (4.3.20) into the labour demand schedule (4.3.30) and then aggregating across households:

$$W_t = \left(\int_0^1 W_{h,t}^{\frac{1}{1-\phi_t^W}} dh\right)^{1-\phi_t^W} \tag{4.3.31}$$

Aggregating over the continuum of firms delivers the aggregate demand for the labour services of household h:

$$N_t^h = \int_0^1 N_{f,t}^h df = \left(\frac{W_{h,t}}{W_t}\right)^{-\frac{\phi_t^W}{\phi_t^W - 1}} N_t \tag{4.3.32}$$

Price setting

Each intermediate goods producer f sells its output $Y_{f,t}$ in both the domestic and foreign market under monopolistic competition. As in Christoffel et al. (2008) and Coenen et al. (2013), it is assumed that the firm charges different prices at home and abroad, setting prices in producer currency regardless of the destination market. Firm f sets prices in a staggered manner as proposed by Calvo (1983). Each intermediate firm optimally resets prices in a given period t either with probability $(1-\theta_H)$ or $(1-\theta_X)$ depending on whether it sells its differentiated output at home or abroad.

Defining $P_{H,f,t}$ the domestic price of good f and $P_{X,f,t}$ its foreign price, all firms that can optimise choose the same price, i.e. $\tilde{P}_{H,f,t} = \tilde{P}_{H,t}$ and $\tilde{P}_{X,f,t} = \tilde{P}_{X,t}$. Following Adolfson et al. (2007), Christoffel et al. (2008) and Du Plessis et al. (2014), among others, it is assumed that firms that are unable to re-optimize, index their price to past inflation and the monetary authority's current inflation target:

$$P_{H,f,t} = (\pi_{H,t-1})^{\chi_H} (\bar{\pi}_{C,t})^{1-\chi_H} P_{H,f,t-1} \tag{4.3.33}$$

$$P_{X,f,t} = (\pi_{X,t-1})^{\chi_X} (\bar{\pi}_{C,t})^{1-\chi_X} P_{X,f,t-1} \tag{4.3.34}$$

where $\pi_{H,t-1} = P_{H,t-1}/P_{H,t-2}$, $\pi_{X,t-1} = P_{X,t-1}/P_{X,t-2}$, $\bar{\pi}_{C,t}$ is the possibly time-varying inflation objective of the domestic monetary authority (in terms of consumer prices), and χ_H and χ_X are indexation parameters. The time-varying inflation target is analogous to a flexible inflation targeting regime. Following Steinbach (2014) and as discussed in Section 4.4.2, its role in the model is to facilitate the transition from the high inflation and interest rates prevalent in the 1990s to the low inflation and interest rate environment thereafter.

Each firm f that optimally resets its price in period t maximises the discounted sum of its expected nominal profits,

$$E_t = \left[\sum_{k=0}^{\infty} \lambda_{t,t+k} \left(\theta_H^k D_{H,f,t+k} + \theta_X^k D_{X,f,t+k}\right)\right] \tag{4.3.35}$$

subject to the price indexation schemes (4.3.33) and (4.3.34), taking as given demand for its differentiated output, $H_{f,t}$ and $X_{f,t}$ (derived below). The stochastic discount factor $\lambda_{t,t+k}$ can be obtained from the consumption Euler equation of the households, while

$$D_{H,f,t+k} = P_{H,f,t}H_{f,t} - MC_t H_{f,t} \tag{4.3.36}$$

$$D_{X,f,t+k} = P_{X,f,t}X_{f,t} - MC_t X_{f,t} \tag{4.3.37}$$

are period-t nominal profits (net of fixed costs), which are distributed to the households.

The optimisation problem in the following first order condition characterising the firm's optimal pricing decision:

$$E_t \left[\sum_{k=0}^{\infty} \lambda_{t,t+k} \theta_H^k \left(\Pi^{\dagger}_{H,t,t+k} \tilde{P}_{H,t} - \phi^H_{t+k} MC_{t+k}\right) H_{f,t+k}\right] = 0 \tag{4.3.38}$$

where we have substituted the indexation scheme (4.3.33), noting that $P_{H,f,t+k} = \Pi^{\dagger}_{H,t,t+k}\tilde{P}_{H,t}$ with $\Pi^{\dagger}_{H,t,t+k} = \prod_{s=1}^{k} \left(\pi_{H,t+s-1}\right)^{\chi_H} \left(\bar{\pi}_{t+s}\right)^{1-\chi_H}$.

The expression in (4.3.38) states that in those markets where price contracts are re-optimised, the optimal price is chosen so as to equate the firm's discounted sum of expected revenues to the discounted sum of expected marginal cost. In the absence of price staggering ($\theta_H = 0$), the factor ϕ^H_t represents a possibly time-varying markup of price over nominal marginal cost, reflecting the degree of monopoly power on the part of the intermediate-good firm.

With the continuum of intermediate-good firms setting the prices for their differentiated products sold domestically according to (4.3.33) and (4.3.38), the aggregate price index $P_{H,t}$ evolves according to:

$$P_{H,t} = \left((1-\theta_H) \left(\tilde{P}_{H,t}\right)^{\frac{1}{1-\phi^H_t}} + \theta_H \left(\left(\pi_{H,t-1}\right)^{\chi_H} \left(\bar{\pi}_{C,t}\right)^{1-\chi_H} P_{H,f,t-1} \right)^{\frac{1}{1-\phi^H_t}} \right)^{1-\phi^H_t} \tag{4.3.39}$$

Similarly, the following first order condition for the firm's optimal pricing decision for its output sold in the foreign market is given by:

$$E_t \left[\sum_{k=0}^{\infty} \lambda_{t,t+k} \theta_X^k \left(\Pi^{\dagger}_{X,t,t+k} \tilde{P}_{X,t} - \phi^X_{t+k} MC_{t+k}\right) X_{f,t+k}\right] = 0 \tag{4.3.40}$$

The aggregate price index set for the differentiated products sold abroad is given by:

$$P_{X,t} = \left((1-\theta_X) \left(\tilde{P}_{X,t}\right)^{\frac{1}{1-\phi_t^X}} + \theta_X \left((\pi_{X,t-1})^{\chi_X} (\bar{\pi}_{C,t})^{1-\chi_X} P_{X,f,t-1} \right)^{\frac{1}{1-\phi_t^X}} \right)^{1-\phi_t^X} \tag{4.3.41}$$

Combining the log-linearised versions of (4.3.38) and (4.3.40) with the log-linearised versions of the aggregate price indices, the following expressions for the log-linear versions of the domestic and export price Phillips-curve relations are obtained:

$$\begin{aligned} \left(\hat{\pi}_{H,t} - \hat{\bar{\pi}}_{C,t}\right) = & \frac{\beta}{1+\beta\chi_H} E_t \left[\hat{\pi}_{H,t+1} - \hat{\bar{\pi}}_{C,t+1}\right] + \frac{\chi_H}{1+\beta\chi_H} \left(\hat{\pi}_{H,t-1} - \hat{\bar{\pi}}_{C,t}\right) \\ & + \frac{\beta\chi_H}{1+\beta\chi_H} E_t \left[\hat{\bar{\pi}}_{C,t+1} - \hat{\bar{\pi}}_{C,t}\right] + \frac{(1-\beta\theta_H)(1-\theta_H)}{\theta_H (1+\beta\chi_H)} \left(\widehat{mc}_t^H + \hat{\phi}_t^H\right) \end{aligned} \tag{4.3.42}$$

$$\begin{aligned} \left(\hat{\pi}_{X,t} - \hat{\bar{\pi}}_{C,t}\right) = & \frac{\beta}{1+\beta\chi_X} E_t \left[\hat{\pi}_{X,t+1} - \hat{\bar{\pi}}_{C,t+1}\right] + \frac{\chi_X}{1+\beta\chi_X} \left(\hat{\pi}_{X,t-1} - \hat{\bar{\pi}}_{C,t}\right) \\ & + \frac{\beta\chi_X}{1+\beta\chi_X} E_t \left[\hat{\bar{\pi}}_{C,t+1} - \hat{\bar{\pi}}_{C,t}\right] + \frac{(1-\beta\theta_X)(1-\theta_X)}{\theta_X (1+\beta\chi_X)} \left(\widehat{mc}_t^X + \hat{\phi}_t^X\right) \end{aligned} \tag{4.3.43}$$

where $\widehat{mc}_t^H = \widehat{mc}_t - \hat{p}_{H,t}$ and $\widehat{mc}_t^X = \widehat{mc}_t - \hat{p}_{X,t}$ represents average real marginal costs for the domestic intermediate-good firm selling in the domestic and foreign markets respectively (expressed as log-deviation from steady state), with $mc_t = MC_t/P_{C,t}$, $p_{H,t} = P_{H,t}/P_{C,t}$ and $p_{X,t} = P_{X,t}/P_{C,t}$.

Foreign intermediate-good firms

Each foreign intermediate goods producer f^* sells its output $Y^*_{f^*,t}$ in the domestic market under monopolistic competition, setting the price in local currency units. Again, it is assumed that firm f^* sets prices in a staggered manner à la Calvo (1983). Each intermediate firm optimally resets prices in a given period t with probability $(1-\theta^*)$. Each firm that does not optimise sets prices according the indexation scheme:

$$P_{IM,f^*,t} = (\pi_{IM,t-1})^{\chi^*} (\bar{\pi}_{C,t})^{1-\chi^*} P_{IM,f^*,t-1} \tag{4.3.44}$$

where $P_{IM,f^*,t} = P^*_{X,f^*,t}$ and $\pi_{IM,t} = P_{IM,t-1}/P_{IM,t-2}$ with $P_{IM,t} = P^*_{X,t}$. The last equality follows from the assumption that the foreign exporting firm sets the price in domestic currency units.

As before, each foreign firm that re-optimises its price in period t maximises the discounted sum of future expected nominal profits:

$$E_t = \left[\sum_{k=0}^{\infty} (\theta^*)^k \lambda^*_{t,t+k} D^*_{f^*,t+k}/S_{t+k} \right] \tag{4.3.45}$$

subject to the price indexation scheme (4.3.44) and the domestic demand for its output, $IM_{f^*,t} = X^*_{f^*,t}$ (derived below) where

$$D^*_{f^*,t} = P_{IM,f^*,t} IM_{f^*,t} - MC^*_t IM_{f^*,t} \tag{4.3.46}$$

with $MC_t^* = S_t P_{Y,t}^*$ representing the foreign intermediate good firm's marginal cost.

The maximisation results in the following first order condition characterising the foreign intermediate good producer's optimal pricing decision for its output sold in the domestic market:

$$E_t \left[\sum_{k=0}^{\infty} (\theta^*)^k \lambda_{t,t+k}^* \left(\Pi_{IM,t,t+k}^{\dagger} \tilde{P}_{IM,t} - \phi_{t+k}^* MC_{t+k}^* \right) IM_{f^*,t+k} / S_{t+k} \right] = 0 \tag{4.3.47}$$

The associated aggregate index evolves according to

$$P_{IM,t} = \left((1-\theta^*) \left(\tilde{P}_{IM,t} \right)^{\frac{1}{1-\phi_t^*}} + \theta^* \left((\pi_{IM,t-1})^{\chi^*} (\bar{\pi}_{C,t})^{1-\chi^*} P_{IM,t-1} \right)^{\frac{1}{1-\phi_t^*}} \right)^{1-\phi_t^*} \tag{4.3.48}$$

while the log-linear import price Phillips curve is then given by:

$$\begin{aligned} \left(\hat{\pi}_{IM,t} - \hat{\bar{\pi}}_{C,t} \right) &= \frac{\beta^*}{1+\beta^*\chi^*} E_t \left[\hat{\pi}_{IM,t+1} - \hat{\bar{\pi}}_{C,t+1} \right] + \frac{\chi^*}{1+\beta^*\chi^*} \left(\hat{\pi}_{IM,t-1} - \hat{\bar{\pi}}_{C,t} \right) \\ &+ \frac{\beta^*\chi^*}{1+\beta^*\chi^*} E_t \left[\hat{\bar{\pi}}_{C,t+1} - \hat{\bar{\pi}}_{C,t} \right] + \frac{(1-\beta^*\theta^*)(1-\theta^*)}{\theta^*(1+\beta^*\chi^*)} \left(\widehat{mc}_t^* + \hat{\phi}_t^* \right) \end{aligned} \tag{4.3.49}$$

Again, $\widehat{mc}_t^* = \hat{s}_t + \hat{p}_{Y,t} - \hat{p}_{IM,t}$ represents the average real marginal cost of the foreign intermediate-good firm, with $p_{IM,t} = P_{IM,t}/P_{C,t}$.

Domestic final-good firms

Following Christoffel et al. (2008), there are four types of final-good firms, combining domestically-produced and imported intermediate goods into four distinct non-tradeable final goods, namely a private consumption good, Q_t^C, a public consumption good, Q_t^G, a private investment good, Q_t^I, and a public investment good, $Q_t^{I_G}$.

The representative final-good firm producing the private consumption good Q_t^C combines domestically produced intermediate consumption goods, H_t^C and imported foreign intermediate consumption goods, IM_t^C using a constant-returns-to-scale CES technology:

$$Q_t^C = \left(\nu_C^{\frac{1}{\mu_C}} \left(H_t^C \right)^{1-\frac{1}{\mu_C}} + (1-\nu_C)^{\frac{1}{\mu_C}} \left(IM_t^C \right)^{1-\frac{1}{\mu_C}} \right)^{\frac{\mu_C}{\mu_C - 1}} \tag{4.3.50}$$

where μ_C represents the intertemporal elasticity of substitution between domestic and imported intermediate consumption goods, while the parameter ν_C measures the share of domestically produced goods in the production of the final consumption good (i.e. home bias).

Defining $H_{f,t}^C$ and $IM_{f^*,t}^C$ as the differentiated output supplied by domestic intermediate-good firm f and the output supplied by foreign exporter f^*, it follows that:

$$H_t^C = \left(\int_0^1 \left(H_{f,t}^C \right)^{\frac{1}{\phi_t^H}} df \right)^{\phi_t^H} \tag{4.3.51}$$

$$IM_t^C = \left(\int_0^1 \left(IM_{f^*,t}^C \right)^{\frac{1}{\phi_t^*}} df^* \right)^{\phi_t^*} \tag{4.3.52}$$

where $\phi_t^H, \phi_t^* > 0$ is defined analogously to ϕ_t^W above and can be interpreted as price markups in the markets for domestic and imported intermediate goods.

The final-good firm takes prices $P_{H,f,t}$ and $P_{IM,f^*,t}$ as given and determines the optimal bundle of intermediate goods by minimising expenditure on the differentiated goods subject to the aggregation constraints (4.3.51) and (4.3.52). This minimisation yields the following set of demand equations for differentiated domestic and foreign intermediate goods:

$$H_{f,t}^C = \left(\frac{P_{H,f,t}}{P_{H,t}}\right)^{-\frac{\phi_t^H}{\phi_t^H - 1}} H_t^C \tag{4.3.53}$$

$$IM_{f^*,t}^C = \left(\frac{P_{IM,f^*,t}}{P_{IM,t}}\right)^{-\frac{\phi_t^*}{\phi_t^* - 1}} IM_t^C \tag{4.3.54}$$

where

$$P_{H,t} = \left(\int_0^1 (P_{H,f,t})^{\frac{1}{1-\phi_t^H}} df\right)^{1-\phi_t^H} \tag{4.3.55}$$

$$P_{IM,t} = \left(\int_0^1 (P_{IM,f^*,t})^{\frac{1}{1-\phi_t^*}} df^*\right)^{1-\phi_t^*} \tag{4.3.56}$$

are the aggregate price indices for the bundles of domestic and foreign intermediate goods, respectively.

Taking the price indices as given, the consumption-good firm chooses the bundles H_t^C and IM_t^C that minimises $P_{H,t}H_t^C + P_{IM,t}IM_t^C$ subject to the aggregation constraint (4.3.50), yielding the demand equations for the domestic and intermediate-good bundles:

$$H_t^C = \nu_C \left(\frac{P_{H,t}}{P_{C,t}}\right)^{-\mu_C} Q_t^C \tag{4.3.57}$$

$$IM_t^C = (1 - \nu_C) \left(\frac{P_{IM,t}}{P_{C,t}}\right)^{-\mu_C} Q_t^C \tag{4.3.58}$$

where

$$P_{C,t} = \left(\nu_C (P_{H,t})^{1-\mu_C} + (1 - \nu_C)\,(P_{IM,t})^{1-\mu_C}\right)^{\frac{1}{1-\mu_C}} \tag{4.3.59}$$

is the price of a unit of the consumption good.

The representative firm producing the non-tradeable final private investment good is modelled in an analogous manner. Specifically, the firm combines domestically-produced intermediate investment goods with imported foreign intermediate investment goods using the following constant-returns-to-scale CES technology,

$$Q_t^I = \left(\nu_I^{\frac{1}{\mu_I}} \left(H_t^I\right)^{1-\frac{1}{\mu_I}} + (1 - \nu_I)^{\frac{1}{\mu_I}} \left(IM_t^I\right)^{1-\frac{1}{\mu_I}}\right)^{\frac{\mu_I}{\mu_I - 1}} \tag{4.3.60}$$

where all other variables related to the production of the intermediate good - the optimal demand for inputs, $H^I_{f,t}$, H^I_t, $IM^I_{f^*,t}$, IM^I_t, as well as the price of a unit of the investment good, $P_{I,t}$ - are defined or derived analogously to that for the consumption good.

In contrast, full home bias is assumed in the production of the non-tradeable final public consumption good, Q^G_t. That is, it is assumed to be a composite made only of domestic intermediate goods, i.e. $Q^G_t = H^G_t$ with

$$H^G_t = \left(\int_0^1 \left(H^G_{f,t} \right)^{\frac{1}{\phi^H_t}} df \right)^{\phi^H_t} \tag{4.3.61}$$

The optimal demand for the intermediate good supplied by firm f is given by

$$H^G_{f,t} = \left(\frac{P_{H,f,t}}{P_{H,t}} \right)^{-\frac{\phi^H_t}{\phi^H_t - 1}} H^G_t \tag{4.3.62}$$

and the price of a unit of the public consumption good is $P_{G,t} = P_{H,t}$.

Similarly, the public investment good, $Q^{I_G}_t$ is assumed to be a composite made up only of domestic intermediate goods, i.e. $Q^{I_G}_t = H^{I_G}_t$, with price $P_{I_G,t} = P_{H,t}$.

Aggregating across firms, the following aggregate demand equations for domestic and foreign intermediate goods hold:

$$H_{f,t} = H^C_{f,t} + H^I_{f,t} + H^{I_G}_{f,t} + H^G_{f,t} = \left(\frac{P_{H,f,t}}{P_{H,t}} \right)^{-\frac{\phi^H_t}{\phi^H_t - 1}} H_t \tag{4.3.63}$$

$$IM_{f^*,t} = IM^C_{f^*,t} + IM^I_{f^*,t} = \left(\frac{P_{IM,f^*,t}}{P_{IM,t}} \right)^{-\frac{\phi^*_t}{\phi^*_t - 1}} IM_t \tag{4.3.64}$$

where $H_t = H^C_t + H^I_t + H^{I_G}_t + H^G_t$ and $IM_t = IM^C_t + IM^I_t$.

Foreign retail firm

A representative foreign retail firm combines differentiated intermediate goods produced domestically by firm f and sold abroad, $X_{f,t}$, using the following CES technology,

$$X_t = \left(\int_0^1 \left(X_{f,t} \right)^{\frac{1}{\phi^X_t}} df \right)^{\phi^X_t} \tag{4.3.65}$$

The foreign retailer takes its input prices $P_{X,f,t}/S_t$ as given and chooses the optimal bundle of differentiated inputs by minimising expenditure on the bundle of differentiated intermediate goods subject to the aggregation constraint (4.3.65), yielding the following demand equation

$$X_{f,t} = \left(\frac{P_{X,f,t}}{P_{X,t}} \right)^{-\frac{\phi^X_t}{\phi^X_t - 1}} X_t \tag{4.3.66}$$

where

$$P_{X,t} = \left(\int_0^1 \left(P_{X,f,t} \right)^{\frac{1}{1-\phi_t^X}} df \right)^{1-\phi_t^X} \tag{4.3.67}$$

is the aggregate price index for the bundle of exported domestic intermediate goods (priced in producer currency).

The retailer takes this price index as given and supplies the quantity of the export bundle, X_t, that satisfies foreign demand. The latter is given by an equation similar in structure to the domestic import equation,

$$X_t = \nu^* \left(\frac{P_{X,t}/S_t}{P^*_{Y,t}} \right)^{-\mu_*} Y_t^* \tag{4.3.68}$$

where μ^* is the price elasticity of exports and ν^* is the export share of the domestic intermediate-good firms. This latter parameter captures specific non-price related foreign preferences for domestic goods. Y_t^* is a measure of overall foreign demand.

4.3.3 Monetary authority

The monetary authority sets the short-term interest rate according to a simple log-linear interest rate rule,

$$\hat{r}_t = \phi_R \hat{r}_{t-1} + (1-\phi_R) \left(\hat{\bar{\pi}}_{C,t} + \phi_\pi \left(\hat{\pi}_{C,t-1} - \hat{\bar{\pi}}_{C,t} \right) + \phi_Y \hat{y}_t \right) + \phi_{\Delta\pi} (\hat{\pi}_{C,t} - \hat{\pi}_{C,t-1}) + \phi_{\Delta Y} (\hat{y}_t - \hat{y}_{t-1}) + \hat{\eta}_t^R \tag{4.3.69}$$

where $\hat{r}_t = \log{(R_t/R)}$ is the log-deviation of the (gross) nominal interest rate from its steady-state value. Similarly, $\hat{\pi}_{C,t} = \log{(\pi_{C,t}/\bar{\pi}_C)}$ denotes the log-deviation of quarter-on-quarter consumer price inflation, $\pi_{C,t} = P_{C,t}/P_{C,t-1}$ from the monetary authority's long-run inflation objective, $\bar{\pi}_C$, while $\hat{\bar{\pi}}_{C,t} = \log{(\bar{\pi}_{C,t}/\bar{\pi}_C)}$ represents the log-deviation of the monetary authority's possibly inflation target from its equilibrium value. The latter is assumed to follow a serially uncorrelated process with mean zero,

$$\hat{\bar{\pi}}_{C,t} = \rho_{\bar{\pi}} \hat{\bar{\pi}}_{C,t-1} + \hat{\eta}_t^{\bar{\pi}} \tag{4.3.70}$$

Additionally, the monetary authority takes into account the current state of economy, where $\hat{y}_t = \widehat{Y_t/z_t}$ denotes the log-deviation of aggregate output from trend output, i.e. the output gap. Finally, η_t^R represents a serially uncorrelated shock to the nominal interest rate. Note that, as in Du Plessis et al. (2014) and based on the findings of Alpanda et al. (2010) for South Africa, it is assumed that the central bank's policy rule does not respond to fluctuations in the real exchange rate.

4.3.4 Fiscal Authority

The fiscal authority purchases the public consumption good, G_t, invests in public capital, $I_{G,t}$, issues bonds to refinance its debt, B_t, makes transfer payments, TR_t, and levies different types of taxes. The fiscal authority's period-by-period budget constraint has the following form:

$$P_{G,t}G_t + P_{I_G,t}I_{G,t} + B_t + TR_t = \tau_t^c P_{C,t}C_t + \tau_t^w W_t N_t + \tau_t^k \left(R_{K,t}u_t - \left(\Gamma_u(u_t) + \delta\right) P_{I,t}\right) K_t + \frac{B_{t+1}}{R_t} \quad (4.3.71)$$

where $P_{G,t}$ and $P_{I_G,t}$ are the prices of the public consumption good and the public investment good respectively which, under the assumption of full home bias, is just equal to the domestic price level, $P_{H,t}$. [62]

Following Leeper et al. (2010), Coenen et al. (2012), Born et al. (2013), and Leeper et al. (2017), among others, the fiscal instruments are assumed to follow the prescriptions of simple feedback rules. These rules embed two features. First, the rules incorporate automatic stabilisers through the inclusion of a contemporaneous response of the relevant fiscal variable to the output gap. Second, all fiscal instruments are permitted to respond to deviations of government debt from its steady-state level in an effort to stabilise public debt. [63]

Spending rules are given by:

$$\hat{g}_t = \phi_G \hat{g}_{t-1} - \theta_{G,Y}\hat{y}_t - \theta_{G,B}\hat{b}_t + \hat{\varepsilon}_t^G \quad (4.3.72)$$
$$\hat{i}_{G,t} = \phi_{I_G}\hat{i}_{G,t-1} - \theta_{I_G,Y}\hat{y}_t - \theta_{I_G,B}\hat{b}_t + \hat{\varepsilon}_t^{I_G} \quad (4.3.73)$$
$$\hat{tr}_t = \phi_{TR}\hat{tr}_{t-1} - \theta_{TR,Y}\hat{y}_t - \theta_{TR,B}\hat{b}_t + \hat{\varepsilon}_t^{TR} \quad (4.3.74)$$

Analogously, tax rules are given by:

$$\check{\tau}_t^w = \phi_W \check{\tau}_{t-1}^w + \theta_{W,Y}\hat{y}_t + \theta_{W,B}\hat{b}_t + \hat{\varepsilon}_t^{\tau^w} \quad (4.3.75)$$
$$\check{\tau}_t^k = \phi_K \check{\tau}_{t-1}^k + \theta_{K,Y}\hat{y}_t + \theta_{K,B}\hat{b}_t + \hat{\varepsilon}_t^{\tau^k} \quad (4.3.76)$$
$$\check{\tau}_t^c = \phi_C \check{\tau}_{t-1}^c + \theta_{C,Y}\hat{y}_t + \theta_{C,B}\hat{b}_t + \hat{\varepsilon}_t^{\tau^c} \quad (4.3.77)$$
$$(4.3.78)$$

where the ' ˇ ' symbol denotes percentage-point deviations from the steady-state tax rate as in Coenen et al. (2013) and the ε's are exogenous AR(1) processes. This type of specification for the so-called fiscal reaction function has its origin in the work of Henning Bohn (see Bohn, 1998 in which the author showed that the sustainability of fiscal policy can be assessed by estimating a fiscal reaction function of the type presented above).[64]. There is also a rich history of investigating fiscal reaction functions in South Africa outside the context of DSGE models (see, for example, Burger et al., 2012; Burger and Marinkov, 2012; and Burger et al., 2015).

The fiscal rules in equations (4.3.76) to (4.3.74) are consistent with the idea that debt stabilization is an important consideration in the formulation of fiscal policy. Additionally, as shown by Ravn et al. (2007), such linear tax rules can in fact approximate optimal rules.

The inclusion of an automatic stabilizer component in the transfer rule is particularly important. Given the assumption that the output gap enters the transfer rule with a negative coefficient, any expansionary fiscal shock which brings about an increase in aggregate activity (and, therefore, a

[62]Note that the aggregate quantity of a household specific variable, $X_{h,t}$ is given by $X_t = \int_0^1 X_{h,t}dh = (1-\omega)X_{i,t} + \omega X_{j,t}$.

[63]The assumptions will be relaxed and simulations run using different specifications of the fiscal rules.

[64]See also Bohn (1995, 2007, 2011)

expansion in employment) by construction induces a reduction in transfers to households. The decline in transfers will in turn offset the possible increase in disposable income of non-Ricardian households stemming from the increase in economic activity and the concomitant increase in labour income. This might dampen the overall impact of the expansionary fiscal shock.

By adjusting these fiscal feedback rules, both on the revenue and expenditure side, the macroeconomic impact of using different instruments to stabilize debt in the face of a shock can be investigated. This can be done by 'switching' the feedback variables in the expenditure and tax equations on and off. By removing these feedback terms from one or more of the equations, the instrument that will respond to a shock in order to stabilize debt can be specified.

Note also that in order to guarantee longer-term debt sustainability, the debt-feedback coefficient ($\theta_{*,B}$) must be non-zero for at least one instrument. Findings in the literature show that it generally suffices to assume a small and inertial response of the chosen instrument(s) to deviations in debt. [65]

4.3.5 Aggregation and market clearing

Given that households within each of the two groups (Ricardian and non-Ricardian) are identical, the aggregate quantity of a household specific variable, $X_{h,t}$, is given by $X_t = \int_0^1 X_{h,t} dh = (1-\omega)X_{i,t} + \omega X_{j,t}$. For example, aggregate consumption is given by $C_t = (1-\omega)C_{i,t} + \omega C_{j,t}$. Any variable that only relates to Ricardians only is given by $X_t = (1-\omega)X_{i,t}$, for example, the aggregate private capital stock is given by $K_t = (1-\omega)K_{i,t}$.

Market clearing in labour markets

Each household h supplies its labour in a monopolistically competitive market. In equilibrium, the total supply of the individual households' differentiated labour service must equal the intermediate-good firm's demand for labour.

$$N_{h,t} = \int_0^1 N^h_{f,t} df = N^h_t \tag{4.3.79}$$

Aggregating over all households h we have

$$\begin{aligned} \int_0^1 N_{h,t} dh &= \int_0^1 N^h_t dh \\ &= \int_0^1 \left(\frac{W_{h,t}}{W_t}\right)^{-\frac{\phi^W_t}{\phi^W_t - 1}} N_t dh \end{aligned} \tag{4.3.80}$$

The aggregate wage sum paid by firms is given by

$$\int_0^1 W_{h,t} N_{h,t} dh = N_t \int_0^1 W_{h,t} \left(\frac{W_{h,t}}{W_t}\right)^{-\frac{\phi^W_t}{\phi^W_t - 1}} dh = W_t N_t \tag{4.3.81}$$

where the first equality is obtained by using the aggregate demand for labour services of variety h (combining equations (4.3.32) and (4.3.79)), while the second equality uses the properties of the aggregate wage index W_t.

[65] The literature on optimal fiscal policy derives two stylised results. First, small, permanent shifts in fiscal instruments is preferred to large, sudden moves. Second, mild countercyclical policies can have stabilising and welfare enhancing effects (Stähler and Thomas, 2012)

Market clearing in the capital market

Market clearing in the rental market for capital services implies that the effective capital utilisation rate satisfies the following condition:

$$u_t K_t = u_t \int_0^1 K_{h,t} dh = \int_0^1 K^s_{f,t} df = K^s_t \tag{4.3.82}$$

Market clearing in the market for domestic intermediate goods

Each intermediate-good producing firm f acts as price setter in domestic and foreign markets. Therefore, in equilibrium, the supply of its differentiated output needs to equal domestic and foreign demand:

$$Y_{f,t} = H_{f,t} + X_{f,t} \tag{4.3.83}$$

Aggregating over the continuum of firms gives the following aggregate resource constraint:

$$\begin{aligned} Y_t &= \int_0^1 Y_{f,t} df = \int_0^1 H_{f,t} df + \int_0^1 X_{f,t} df \\ &= \int_0^1 \left(\frac{P_{H,f,t}}{P_{H,t}}\right)^{-\frac{\phi_t^H}{\phi_t^H - 1}} H_t df + \int_0^1 \left(\frac{P_{X,f,t}}{P_{X,t}}\right)^{-\frac{\phi_t^X}{\phi_t^X - 1}} X_t df \end{aligned} \tag{4.3.84}$$

Expressing (4.3.84) in nominal terms gives the following nominal resource constraint:

$$\begin{aligned} P_{Y,t} Y_t &= \int_0^1 P_{H,f,t} H_{f,t} df + \int_0^1 P_{X,f,t} X_{f,t} df \\ &= H_t \int_0^1 P_{H,f,t} \left(\frac{P_{H,f,t}}{P_{H,t}}\right)^{-\frac{\phi_t^H}{\phi_t^H - 1}} df + X_t \int_0^1 P_{X,f,t} \left(\frac{P_{X,f,t}}{P_{X,t}}\right)^{-\frac{\phi_t^X}{\phi_t^X - 1}} df \\ &= P_{H,t} H_t + P_{X,t} X_t \end{aligned} \tag{4.3.85}$$

where the second-to-last equality follows from the aggregate demand relationships for the domestic intermediate goods sold in home and foreign markets, $H_{f,t}$ and $X_{f,t}$, while the last equality uses the properties of the aggregate price indices, $P_{H,t}$ and $P_{X,t}$.

Market clearing in market for imported intermediate goods

Each foreign exporter, f^*, acts as price setter in the domestic market. Hence, in equilibrium, the supply of its differentiated good must equal demand, $IM_{f^*,t}$.

Aggregating over the continuum of foreign firms f^*, we have

$$\int_0^1 IM_{f^*,t} df^* = \int_0^1 \left(\frac{P_{IM,f^*,t}}{P_{IM,t}}\right)^{-\frac{\phi_t^*}{\phi_t^* - 1}} IM_t df^* \tag{4.3.86}$$

Market clearing in the final-goods market

Market clearing in the fully competitive, final-good market implies:

$$Q_t^C = C_t \tag{4.3.87}$$
$$Q_t^I = I_t + \Gamma_u(u_t)K_t \tag{4.3.88}$$
$$Q_t^{I_G} = I_{G,t} \tag{4.3.89}$$
$$Q_t^G = G_t \tag{4.3.90}$$

Combining the market-clearing conditions for domestic intermediate-good and final-good markets results in an expression for the nominal aggregate resource constraint:

$$\begin{aligned} P_{Y,t}Y_t &= P_{H,t}H_t + P_{X,t}X_t \\ &= P_{C,t}C_t + P_{I,t}\left(I_t + \Gamma_u(u_t)K_t\right) + P_{I_G,t}I_{G,t} + P_{G,t}G_t + P_{X,t}X_t \\ &- P_{IM,t}\left(IM_t^C + IM_t^I\right) \end{aligned} \tag{4.3.91}$$

where the last equality uses the demand functions for the bundles of the domestic and foreign intermediate goods used in the production of the final consumption and investment goods, H_t^C and H_t^I, as well as IM_t^C and IM_t^I, along with the prices of the two types of final goods, $P_{C,t}$ and $P_{I,t}$. Finally, under the assumption of full home bias in government consumption and investment, $P_{G,t} = P_{I_G,t} = P_{H,t}$.

Market clearing in the domestic bond market

The equilibrium holdings of domestic bonds evolve over time according to the fiscal authority's budget constraint, reflecting the fiscal authority's need to issue debt in order to finance its deficit. That is, new bond issuance is equal to the difference between government expenditure and revenue

$$\left[\frac{B_{t+1}}{R_t} - B_t\right] = GE_t - GR_t \tag{4.3.92}$$

with $GE_t \equiv$ *total government expenditure* and $GR_t \equiv$ *total government revenue*. At any given point in time, the supply of domestic bonds is fully elastic and matches the (net) holdings of domestic bonds accumulated by households:

$$B_t = \int_0^1 B_{h,t}dh \tag{4.3.93}$$

Market clearing in the foreign bond market

At any given point in time, the supply of internationally traded foreign bonds is fully elastic and matches the (net) holdings of foreign bonds accumulated by domestic households,

$$B_t^* = \int_0^1 B_{h,t}^*dh \tag{4.3.94}$$

4.3.6 Net foreign assets and the trade balance

The domestic economy's net foreign assets equal the economy-wide net holdings of foreign bonds (denominated in foreign currency) and evolve according to

$$\frac{B^*_{t+1}}{R^*_t} = B^*_t + \frac{TB_t}{S_t} \tag{4.3.95}$$

where

$$TB_t = P_{X,t}X_t - P_{IM,t}IM_t \tag{4.3.96}$$

is the domestic economy's trade balance.[66] For convenience, net foreign assets, as well as the trade balance, can be expressed as a share of domestic output. That is, $s_{B^*,t+1} = S_t B^*_{t+1}/P_{Y,t}Y_t$ and $s_{TB,t} = TB_t/P_{Y,t}Y_t$.

4.3.7 Foreign economy

Following Steinbach (2014) and Du Plessis et al. (2014), the foreign economy is modelled as a standard three-equation closed economy DSGE model:

$$\hat{y}^*_t = E_t\hat{y}^*_{t+1} - \frac{1}{\sigma^*}\left(\hat{r}^*_t - E_t\hat{\pi}^*_{t+1} + \hat{\varepsilon}^{y^*}_t\right) \tag{4.3.97}$$

$$\hat{\pi}^*_t = \beta^* E_t\hat{\pi}^*_{t+1} + \kappa^*\hat{y}^*_t + \hat{\varepsilon}^{\pi^*}_t \tag{4.3.98}$$

$$\hat{r}^*_t = \phi^*_R\hat{r}^*_{t-1} + (1-\phi^*_R)\left[\phi^*_\pi\hat{\pi}^*_t + \phi^*_y\hat{y}^*_t\right] + \eta^{R^*}_t \tag{4.3.99}$$

where $\hat{y}^*_t$, $\hat{\pi}^*_t$ and $\hat{r}^*_t$ represent foreign output, inflation and the policy rate. $\hat{\varepsilon}^{y^*}_t$ and $\hat{\varepsilon}^{\pi^*}_t$ are AR(1) shock processes.

4.4 Estimation

4.4.1 Estimation methodology

In order to cast the model in state-space form, the model equations are log-linearised.[67] The state-space representation of the model is given by:

$$S_t = FS_{t-1} + Q\epsilon_t \tag{4.4.1}$$

$$Y_t = M + HS_{t-1} + \eta_t \tag{4.4.2}$$

with

[66] Importantly, the existence of a financial intermediation premium ensures that domestic holdings of foreign bonds are zero in the non-stochastic steady state.

[67] The full set of log-linear equations are presented in Appendix C.

$$\begin{bmatrix} \epsilon_t \\ \eta_t \end{bmatrix} \sim N \left(0, \begin{bmatrix} \sigma & 0 \\ o & R \end{bmatrix} \right) \tag{4.4.3}$$

where the state vector S_t contains the model's endogenous variables, while Y_t is the vector of observed variables. The data series used are discussed below. The matrices F and Q are functions of the model parameters, M contains the equilibrium information relating to the observable variables, and H is a mapping function that maps the model variables to the data. ϵ_t is a vector of innovations to the structural shocks, while η_t is the vector of measurement errors (Steinbach, 2014). The model is estimated using Bayesian techniques, following the approach described in An and Schorfheide (2007) and is implemented in Dynare, a MATLAB pre-processor which allows for the Bayesian estimation of DSGE models.[68]

According to An and Schorfheide (2007), Bayesian estimation offers several advantages when it comes to estimating DSGE models. A major advantage is that Bayesian estimation is by its nature system-based and is, therefore, appropriate for taking large-scale DSGE models to the data. This contrasts to GMM estimators which estimate individual (i.e. equation-by-equation) equilibrium relationships. A further advantage of Bayesian estimation is that it allows the researcher to incorporate additional information with respect to the model parameters by specifying appropriate prior distributions over said parameters. This formalises the use of prior and/or external information that was prevalent in earlier studies in estimating the parameters of a possibly large and complex DSGE model. As such, Bayesian estimation occupies the middle ground between full maximum likelihood estimation and pure calibration (Steinbach, 2014).

4.4.2 Data

A total of twenty-two observable time series are used, comprising both domestic and foreign macroeconomic variables. The sample period runs from 1994Q1 to 2018Q4. Data for the South African economy was largely sourced from the South African Reserve Bank (SARB) Quarterly Bulletin.[69] The exceptions are CPI and producer price inflation data that were sourced from Statistics South Africa. Following Steinbach (2014), data for South Africa's trading partners was sourced from the Global Projection Model of the Center for Economic Research and its Applications (CEPREMAP). Foreign variables were constructed as the trade-weighted sum of the country-specific quantities. Table 4.1 lists the time series used as well as their respective sources. Note that the nominal effective exchange rate is the indirect measure published by the SARB, implying that an increases denotes an appreciation. This index was inverted before being used in estimation for conform to the model definition of the exchange rate, i.e. a decrease signifies an appreciation.

Given the fact that the log-linearised model presents a stylised representation of the economy, fifteen of the twenty-two observable variables are included with measurement error to account for possible mismatch between the theoretical model variables and their real-world counterparts. To that end, R in equation (4.4.3) is calibrated so that measurement error accounts for approximately 15% of the variation in the observed data.

[68] In this application, the estimation procedure uses the Metropolis-Hastings (MH) Markov-Chain Monte Carlo (MCMC) algorithm with 300,000 draws for two chains (with a burn-in of 0.15). To ensure that the tails of the posterior mode are identified, the scale used for the jumping distribution is adjusted to ensure an acceptance rate of approximately 28%.

[69] Note that public expenditure and investment data used in the estimation of the fiscal reaction functions is sourced from the System of National Accounts, while revenue data is sourced from National Revenue Account data. Both sets of data are documented in the Quarterly Bulletin.

Table 4.1: Observable variables

Variable	Description	Source
Domestic economy		
$\Delta\ln(\tilde{Y}_t)$	Real GDP	
$\Delta\ln(\tilde{C}_t)$	Private consumption	
$\Delta\ln(\tilde{G}_t)$	Government consumption	
$\Delta\ln(\tilde{I}_t)$	Private sector fixed investment	
$\Delta\ln(\tilde{I}_{G,t})$	Public sector investment	
$\Delta\ln(\tilde{X}_t)$	Total exports	
$\Delta\ln(\tilde{M}_t)$	Total imports	South African Reserve Bank
$\Delta\ln(\tilde{S}_t)$	Nominal effective exchange rate	
$\Delta\ln(\tilde{E}_t)$	Non-agricultural employment	
$\Delta\ln(\tilde{W}_t)$	Real remuneration per worker in the non-agricultural sector	
$\Delta\ln(\tilde{TR}_t)$	Government transfers to households	
$\tilde{R}_t$	Repo rate	
$\tilde{\pi}_{I,t}$	Investment deflator	
$\tilde{\pi}_{H,t}$	PPI inflation	Statistics South Africa
$\tilde{\pi}_{C,t}$	CPI inflation	
$\tilde{\bar{\pi}}_{C,t}$	Inflation target	
$\Delta\tilde{\tau}^w_t$	Labour tax rate	Author's calculations
$\Delta\tilde{\tau}^k_t$	Capital tax rate	
$\Delta\tilde{\tau}^c_t$	Consumption tax rate	
Foreign economy		
$\Delta\ln(\tilde{Y}^*_t)$	Real GDP (trade weighted)	
$\tilde{R}^*_t$	Policy interest rates (trade weighted)	GPM, CEPREMAP
$\tilde{\pi}^*_t$	CPI inflation (trade weighted)	

Calculation of tax rates

Effective tax rates are calculated as follows:

Labour tax rate (τ^w)

The labour tax rate is calculated as the ratio between personal income taxes and total nominal compensation of employees, i.e.

$$\tau^w_t = \frac{TP_t}{COMP_t} \tag{4.4.4}$$

where TP_t is total personal income taxes and $COMP_t$ is total compensation. Both constituent series are sourced from the SARB Quarterly Bulletin.

Capital tax rate (τ^k)

The capital tax rate is calculated as the ratio between the sum of total corporate taxes and taxes on property and net operating surplus, i.e.

$$\tau_t^k = \frac{TC_t + TPROP_t}{NOS_t} \tag{4.4.5}$$

where TC_t is total corporate taxes, $TPROP_t$ is taxes on property, and NOS_t is net operating surplus. Constituent series are sourced from the SARB Quarterly Bulletin.

Consumption tax rate (τ^c)

The capital tax rate is calculated as the ratio between total taxes on goods and services and the difference between private consumption and taxes on goods and services, i.e.

$$\tau_t^c = \frac{TGOOD_t}{CP_t - TGOOD_t} \tag{4.4.6}$$

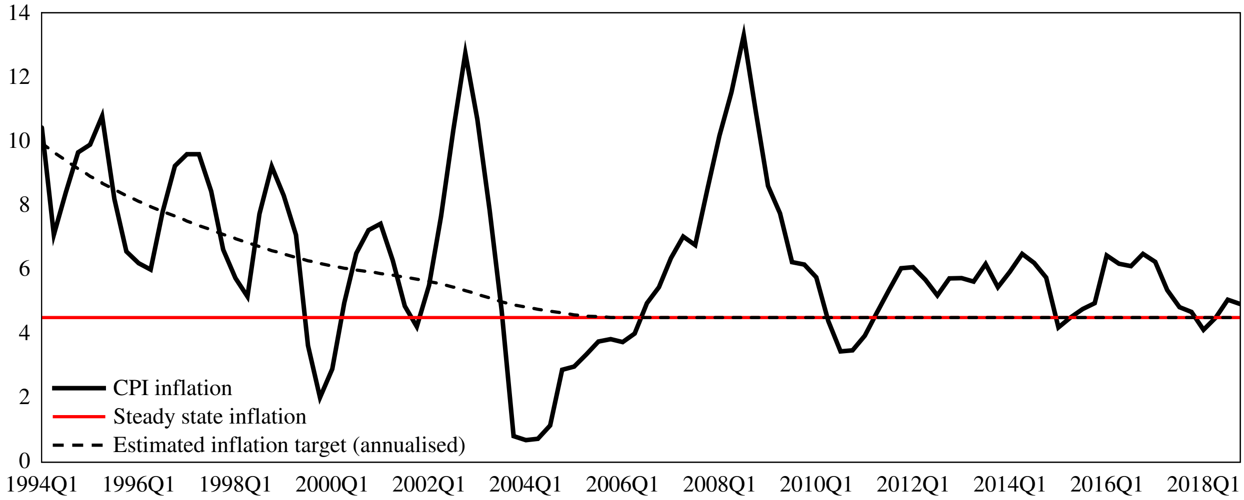
where $TGOOD_t$ is taxes on goods and services and CP_t is (nominal) private consumption spending. Constituent series are sourced from the SARB Quarterly Bulletin.

As mentioned in Born et al. (2013), using average effective tax rates may be problematic for several reasons. First, there is no clear division between labour and capital taxes, which are theoretical constructs. Second, using average effective tax rates are problematic in the presence of a progressive labour income tax schedule as it is legislated marginal tax rates rather than average effective tax rates that affect behaviour. Nevertheless, for comparability with the existing literature, average effective tax rates are constructed. While this is clearly a simplifying assumption, it can be justified on grounds that the dynamics of marginal and average tax rates are very similar.

Inflation targeting and the model structure

The SARB officially adopted inflation targeting in the year 2000. However, it can be argued that the SARB unofficially targeted some measure of inflation throughout the 1990s. That being said, the official measure only entered the target range of 3% to 6% 2003Q4 - close to four years after the (official) implementation of inflation targeting. The period before was characterised by excessively high inflation and interest rates. Following Steinbach (2014), it is assumed that the unofficial inflation target during this period most likely exceeded the model's calibrated steady state inflation rate of 4.5%. To that end, the model's inflation target variable $\tilde{\bar{\pi}}_{C,t}$ enters as an additional observable variable, with the time-varying target calculated by means of a Hodrick-Prescott filter which converges to 4.5% (the mid-point of the official target band) in 2004. Figure 4.1 plots this estimated inflation target. The inclusion of this time-varying inflation target does not affect the model's steady state or model dynamics, but it does affect estimation of the parameters in the Phillips curves and the Taylor rule.

Figure 4.1: Inflation target midpoint estimate



4.4.3 Calibration

While the model is estimated using Bayesian techniques, a sizeable share of the parameters is nevertheless calibrated. In particular, those parameters that affect the model's non-stochastic steady state, as well as those parameters that are not suitably identified, are calibrated using external information.[70][71].

The model's steady state growth rate, g_z, is set equal to 1.0067, which implies a steady state economy-wide growth rate of 2.7% - roughly the average growth rate of GDP over the sample. Some of the model's key steady-state ratios are fixed to match their empirical counterparts. These include the expenditure shares of private consumption, private investment, public sector investment and government consumption, which are set equal to 62.2%, 12.6%, 5.7%, and 19.5% of nominal GDP respectively. The export and import shares are set to 28.2%, ensuring balanced trade in steady state.

As mentioned above, the steady state rate of inflation in the model, $\bar{\pi}$, is set equal to the mid-point of the SARB's official target band, yielding an annual rate of 4.5%. Conditional on the model's steady state growth rate and steady state rate of inflation, the discount factor β is chosen to be deliver an annualised steady state nominal interest rate of 9.8% - roughly equal to the average policy interest rate over the sample. Since $R = (\bar{\pi} g_z)/\beta$, this implies that $\beta = 0.994$.

The share of private consumption in the aggregate consumption bundle, α_G, is set equal to 0.75. This parameter value implies roughly equal marginal utilities of private (Ricardian) consumption and government consumption (Coenen et al., 2013). On the supply side, the capital share of production is set equal to 0.3, i.e. $\alpha = 0.3$. The share of private capital in the CES aggregate, α_K, is set equal to 0.9. This ensures roughly equal the marginal products of private and public capital. The depreciation rates for private capital, δ, and public capital, δ_G, are set equal to 0.015 and 0.008 respectively, implying annual deprecation rates of 6% and 3.5%. The parameters that govern the adjustment cost of capital utilisation, $\gamma_{u,1}$ and $\gamma_{u,2}$ are calibrated as follows: $\gamma_{u,1}$ is pinned down by the steady state calculation as $\gamma_{u,1} = r_K/\bar{\pi}$, while $\gamma_{u,2}$ is set such that the ratio of the two parameters is equal to 0.1, matching the parameterisation in Steinbach (2014).

Turning to the fiscal sector, steady-state tax rates are calibrated to match the average effective tax rates in the data, measured as the revenue-to-tax base ratio. Specifically, the steady state

[70] See Appendix C for details on the computation of the steady state.

[71] Identification analysis was carried out in Dynare. The identification procedures embedded in Dynare toolbox are largely based on Iskrev (2010a,b)

Table 4.2: Calibrated parameters

β	Discount factor	0.994	g_z	Permanent technology growth	1.0067
$\bar{\pi}$	Steady state inflation	1.011	α_G	Share of private consumption in CES aggregate	0.75
α	Capital share in production	0.3	α_K	Share of private capital in CES aggregate	0.9
δ	Depreciation rate: private capital	0.015	δ_G	Depreciation rate: public capital	0.008
B_Y	Government debt-to-GDP ratio	0.5	σ_L	Labour supply elasticity	5
ν_C	Consumption domestic share	0.64	ν_I	Investment domestic share	0.52
θ_W	Calvo: wage setting	0.75	χ_W	Indexation: wage setting	0.75
ϕ_W	Wage setting markup	1.05	ϕ_H	Domestic price markup	1.1
μ_C	Subst. elasticity: consumption	1.5	μ_I	Subst. elasticity: investment	1.5
μ^*	Subst. elasticity: foreign	1.25	π^*	Foreign inflation	1.005
s_C	Private consumption share	0.622	s_I	Private investment share	0.126
s_{I_G}	Public investment share	0.057	s_G	Government consumption share	0.195
s_X	Export share	0.282	s_{IM}	Import share	0.282

values for indirect (or consumption) taxes, τ^c, labour taxes, τ^w, and capital taxes, τ^k, are set equal to 16.7%, 19.1%, and 20.3% respectively. Regarding government debt, the steady-state debt-to-GDP ratio is fixed at 50% per annum. This is higher than the sample average of approximately 37%. However, South Africa's debt-to-GDP has increased substantially over the last decade, from below 25% in 2008 to close to 60% in 2018. Given the current low-growth environment and the increasing demands on the fiscus, this trend is likely to continue into the foreseeable future. As such, the steady state debt-to-GDP is calibrated at a relatively conservative 50% per annum.

The inverted Frisch elasticity of labour supply, σ_L is set equal to 5, following Steinbach (2014). As discussed in Appendix C, the shares of domestic production in aggregate consumption and investment, ν_C and ν_I, are calibrated so as to ensure that the steady state ratios of total imports and exports to GDP match their sample means of roughly 28%. Following Steinbach, 2014), θ_W and χ_W are both set equal to 0.75. The calibration implies that wage contracts are re-optimised once a year, with a relatively high degree of indexation to past inflation. The steady state wage markup, ϕ_W, follows Adolfson et al. (2007) and Steinbach (2014) and is calibrated at 1.05, while ϕ_H is calibrated to 1.1. The substitution elasticities for consumption, investment and foreign goods and are calibrated to 1.5, 1.5 and 1.25 respectively. Steady state foreign inflation is calibrated to match the sample mean of roughly 2% per annum.

4.4.4 Prior distributions

The prior means for the set of estimated parameters are summarised in Table C.1 and Table C.3 in Appendix C and largely follows Christoffel et al. (2008), Leeper et al. (2010), Coenen et al. (2013), and Steinbach (2014).

As the share parameters, ω and $\bar{\omega}$, are bounded between zero and one, they are assumed to follow a beta distribution. Similarly, the degree of habit persistence is also assumed to follow a beta distribution around 0.65. The prior for the investment adjustment cost parameter, ϕ_i, follows a normal distribution with a mean of 8.

Given that the elasticities ν_G and ν_K in the CES aggregates for consumption and the capital stock are restricted to be positive, the prior is assumed to follow a gamma distribution with mean 1 (corresponding to the Cobb-Douglass case) and standard deviation 0.2.

Turning to price setting, the Calvo (θ's) and indexation parameters (χ's) are bounded to lie between zero and one and are assumed to follow beta distributions. Importantly, the size of the prior means on the Calvo parameters reflect the stylized fact that inflation is relatively sticky.

Following Smets and Wouters (2003), among others, the priors for the Taylor rule parameters are fairly standard. However, following Steinbach (2014), a larger weight is placed on both output parameters in order to allow for flexible inflation targeting.

Regarding the feedback coefficients in the fiscal rules, $\theta_{\cdot,Y}$ and $\theta_{\cdot,B}$, gamma distributions with means of around 0.5 and standard deviations of 0.3 are adopted. For the smoothing coefficients embedded in the fiscal rules, $\rho_{\cdot}$, beta distributions are adopted.

Finally, the persistence of structural shocks are all assumed to follow a beta distribution around a mean of 0.85 with standard deviation of 0.1, while the standard deviations of the shocks themselves are assumed to follow inverse-gamma distributions around a mean of 0.1 with standard deviation of 2.

4.4.5 Estimation results

Estimation results are summarised in Table C.1, while Figure C.3 presents the prior and posterior distributions.

The posterior mean of the share of non-Ricardian households is $\omega = 0.233$ which is similar to estimates in the literature for developed economies. This relatively low estimate might seem at odds with the stylized facts associated with the South African income distribution. South Africa is a highly unequal society with a large share of the population having little to no access to financial services and/or saving and investment mechanisms. This would point to a larger share of non-Ricardian households in the model set-up. However, individuals in higher income groups also spend more, with the larger share of total consumption expenditure focused in the middle- and top income groups. Given that the model seeks to match the *dynamics* in total consumer spending, combined with the fact that higher-income groups likely dominate aggregate spending dynamics, it would follow that the estimated share of non-Ricardian consumers would be on the low side.

As in Coenen et al. (2013), the model also allows transfer shocks to play a distributional role, the strength of which depends on the share parameter $\bar{\omega}$. However, given an estimate of 0.46, the overall impact is relatively small.

The posterior mean estimate of the elasticity of substitution between private and government consumption goods is $\nu_G = 1.013$, suggesting that the two goods enter the household's utility function as weak substitutes. In contrast, at 0.921, the estimated elasticity of substitution between private and public capital, ν_k, gives rise to modest complementarities in composite capital.

Turning to other parameters of interest, the investment adjustment cost parameter is substantially higher than the prior mean, while there is a high degree of habit persistence in aggregate Ricardian consumption ($\kappa = 0.891$). The estimated Calvo parameters are rather high. These estimates suggest that the Phillips curves within the model are rather flat or, in other words, that the sensitivity of inflation with respect to movements in marginal costs is low. [72] The inflation indexation parameter for domestic prices is estimated around 0.5, i.e. equal weight is place on past inflation relative to the current inflation target. For export and import prices, this weight is smaller than 0.5.

[72] That being said, as mentioned in Christoffel et al. (2008), the high estimates for the Calvo parameters do not necessarily imply a high degree of nominal rigidity. The reason is that the Calvo-style Phillips curve, in general, does not permit the separate identification of nominal and real rigidities which jointly influence the price-setting behaviour of firms. The inclusion of alternative sources of real rigidities could allow for the re-interpretation of the Calvo parameter estimates without affecting the slope coefficient of the Phillips curve (Christoffel et al., 2008).

The posterior estimates for the Taylor rule imply a large weight on interest rate stabilisation. In addition, the while the response to changes in inflation is smaller than under the prior, the response to changing output levels is more pronounced. In all, the estimates suggest that while inflation targeting remains the main objective, output fluctuations (and the level of the output gap) also feature in monetary policy decisions.

Turning to the parameters of the fiscal rules, expenditure items are found to react less strongly to movements in output than taxes, with estimates of $\theta_{G,Y} = 0.167$, $\theta_{I_G,Y} = 0.216$ and $\theta_{TR,Y} = 0.204$.[73] In contrast, there is relatively strong evidence of automatic stabiliser in the tax rules, with estimates of $\theta_{W,Y} = 0.305$, $\theta_{K,Y} = 0.507$ and $\theta_{C,Y} = 0.356$. Apart from public sector investment and transfers, debt feedback coefficients are broadly similar across the different expenditure and tax rules, with the mean posterior estimates coming in at around 0.15. In contrast, at $\theta_{I_G,B} = 0.554$, the debt feedback coefficient in the public sector investment rule is quite large, suggesting strong use of public sector investment to stabilise public debt. This could reflect the apparent willingness of South African authorities to cut back on infrastructure budgets in the face of worsening fiscal outcomes.

The estimates for the persistence of shocks indicate that the various technology shocks and risk premium shocks are most persistent, while the fiscal shocks are least persistent. Consistent with the high weight placed on interest rate smoothing, monetary policy shocks display a low degree of volatility. Apart from public sector investment and transfer shocks, export markup shocks are the most volatile, possibly reflecting the large weight of commodities in South Africa's export basket.

4.4.6 Identification and sensitivity

The identification analysis is based on Ratto (2008) and Ratto and Iskrev (2011). Weak identification implies that changes in a particular parameter are compensated for by linear combinations of one or more other parameters (Iskrev (2010b)), or that changes in a particular parameter have a negligible effect on the model moments (Andrle (2010)).

The identification analysis from Figures C.2, C.3, and C.4 in Appendix C shows that all model parameters are identified in the model at the posterior mean. Figure C.3 plots the identification strength at the posterior mean. Parameters are ranked in increasing order of identification strength. From the top panel in Figure C.3, we see that all parameters are identified, i.e. no value is exactly zero.

The bottom panel suggests that all parameters have a non-negligible effect on the first- and second-order moments. Additionally, a desirable characteristic is that the relatively weaker identified parameters have a lesser effect on the model moments (Hollander and van Lill, 2018).

Finally, the posterior density estimates (Figure C.5, Appendix C) and the convergence diagnostic statistics (Figures C.6 and Figure C.7 in Appendix C) show that there is no clear indication of a problem with the optimizer.[74]

4.4.7 Model fit and historical decomposition

Table 4.3 compares several theoretical moments implied by the model to those of the observed data series in order to determine how well the model fits the data.

[73]Note the signs attached to the different coefficients in the fiscal rules above. Both automatic stabilisers and the reaction to debt enter the fiscal rules with negative signs.

[74]Figure C.5 shows the log-posterior likelihood functions and log-likelihood kernels. If the estimated mode is the local mode, it should be at the maximum of the posterior likelihood. Figure C.6 and Figure C.7 presents the multivariate and univariate convergence diagnostic statistics (Brooks and Gelman, 1998). The convergence of the estimates eliminates bimodal or poorly identified parameter distributions.

Table 4.3: Model and data moments

	$\sigma(x_t)$		$\rho(x_t, x_{t-1})$		$\rho(x_t, y_t)$	
	Model	Data	Model	Data	Model	Data
$\Delta\ln(\tilde{Y}_t)$	1.875	0.600	0.194	0.534	1.000	1.000
$\Delta\ln(\tilde{C}_t)$	0.971	0.706	0.523	0.748	0.184	0.630
$\Delta\ln(\tilde{G}_t)$	0.196	0.903	0.587	0.449	-0.127	0.245
$\Delta\ln(\tilde{I}_t)$	3.593	2.483	0.713	0.279	-0.025	0.562
$\Delta\ln(\tilde{I}_{G,t})$	4.433	4.311	0.431	0.364	0.005	0.135
$\Delta\ln(\tilde{X}_t)$	7.065	5.063	0.225	-0.115	0.877	0.357
$\Delta\ln(\tilde{M}_t)$	2.810	3.749	0.519	0.063	-0.019	0.397
$\Delta\ln(\tilde{S}_t)$	5.115	5.538	-0.005	0.226	0.306	0.039
$\Delta\ln(\tilde{E}_t)$	1.613	0.687	0.312	0.284	0.882	0.377
$\Delta\ln(\tilde{W}_t)$	1.802	1.633	0.186	-0.234	0.128	0.095
$\Delta\ln(\tilde{TR}_t)$	7.893	8.138	-0.106	-0.398	-0.084	-0.028
$\Delta\tilde{\tau}^w_t$	1.184	1.082	-0.049	-0.449	0.434	-0.073
$\Delta\tilde{\tau}^k_t$	2.398	2.315	-0.081	-0.391	0.355	0.023
$\Delta\tilde{\tau}^c_t$	1.339	1.242	-0.082	-0.473	0.433	0.002
$\tilde{R}_t$	1.339	0.979	0.964	0.951	-0.009	-0.015
$\tilde{\pi}_{C,t}$	1.298	0.794	0.747	0.622	-0.122	-0.016
$\tilde{\pi}_{H,t}$	1.595	1.267	0.660	0.561	-0.142	0.264
$\tilde{\pi}_{I,t}$	1.384	1.185	0.664	0.519	-0.098	0.146

Note: Time series x_t are the respective variables in the first column, while y_t denotes the growth rate of output, $\Delta\ln(\tilde{Y}_t)$.

A comparison of the standard deviations (Columns (2) and (3) in Table 4.3) shows that the model generally predicts a larger degree of volatility than observed in the data, mirroring the results in Steinbach (2014). Nevertheless, the relative magnitudes correspond. An important feature of the model, particularly in an open economy setting, is that volatile variables such as imports, exports and the exchange rate are accurately captured. The same rings true for the main variables of interest in this study, namely the fiscal variables. The model does an admirable job in capturing the volatility in the fiscal variables, including the relatively volatile tax rates.

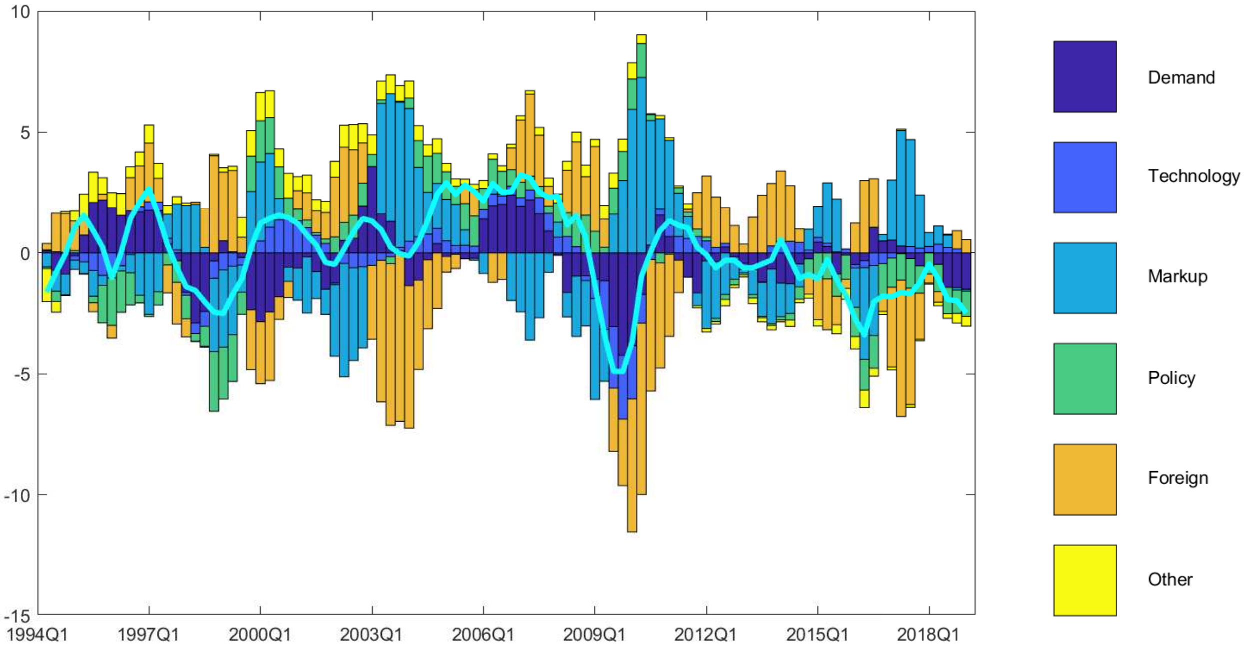
Columns (4) and (5) compare the model-implied persistence with the actual persistence observed in the data. Apart from one or two exceptions, the model generally succeeds in matching the persistence observed in the data.

The final two columns of Table 4.3 contains the cross-correlation of the selected variables with output growth. There is a large degree of similarity - both in terms of sign and magnitude - between the model generated correlations and those observed in the data. However, the model fails to replicate the (slight) pro-cyclical nature of government spending, private investment and imports observed in the data. That being said, in general the model succeeds in matching the observed data.

Figure 4.2 decomposes the model's estimate of year-on-year GDP growth (relative to the mean) into contributions from each of the estimated structural shocks.[75]

[75]The demand shock group includes shocks to the domestic risk premium, government consumption and government investment. The technology shock group comprises the permanent technology shock, the transitory technology shock and the investment-specific technology shock, while the markup shock group consists of the wage markup, the domestic price markup and the export price markup shocks. The policy shock group comprises the monetary policy shock as well as shocks to the various fiscal variables. Finally, the foreign shock group

Figure 4.2: Historical shock decomposition of GDP growth



Developments around the exchange rate, as captured in both the markup and foreign groupings, dominated GDP growth over the period 2000 to 2003, while demand contributed negatively over the same period. This likely reflected increased risk aversion around the turn of the century related to the emerging market crisis of the late 1990s. Between 2006 and 2008, innovations to demand and technology contributed positively to growth, while being offset by adverse supply shocks (as captured in the markup group). The negative impact of global developments becomes apparent during the GFC, both through a decline in foreign demand and a shock to export markups. The latter likely reflects the substantial fall in international commodity prices experienced at the time. Additionally, while domestic demand shocks contributed positively to growth in the lead-up to the crisis, the contribution turned negative during the crisis and has remained subdued since. The recovery in the global economy, combined with substantial monetary easing internationally, supported growth between 2012 and 2015. However, the stronger rand exchange rate and drop in commodity prices weighed on export markups. This situation has reversed since 2017, with higher commodity prices and a weaker rand exchange rate countering the slowdown in global growth to some extent. However, the former does not appear to fully offset the negative contributions from domestic demand and less accommodative domestic policy, both monetary and fiscal, over this period.

4.4.8 Model dynamics

Figures 4.3 to 4.6 plot impulse responses of key model variables in response to structural shocks common to standard New Keynesian DSGE models. Four distinct shocks are investigated: a shock to the domestic policy interest rate, a transitory technology shock, a shock to the domestic price markup shock, and a shock to foreign demand. The interest rate shock gives information on the monetary policy transmission mechanism, while the other three shocks are examples of supply, cost-push and demand shocks.[76]

includes the external risk premium shock, the import price markup shock, and shocks to the foreign variables, including foreign output.

[76]Fiscal policy shocks are discussed in the next section.

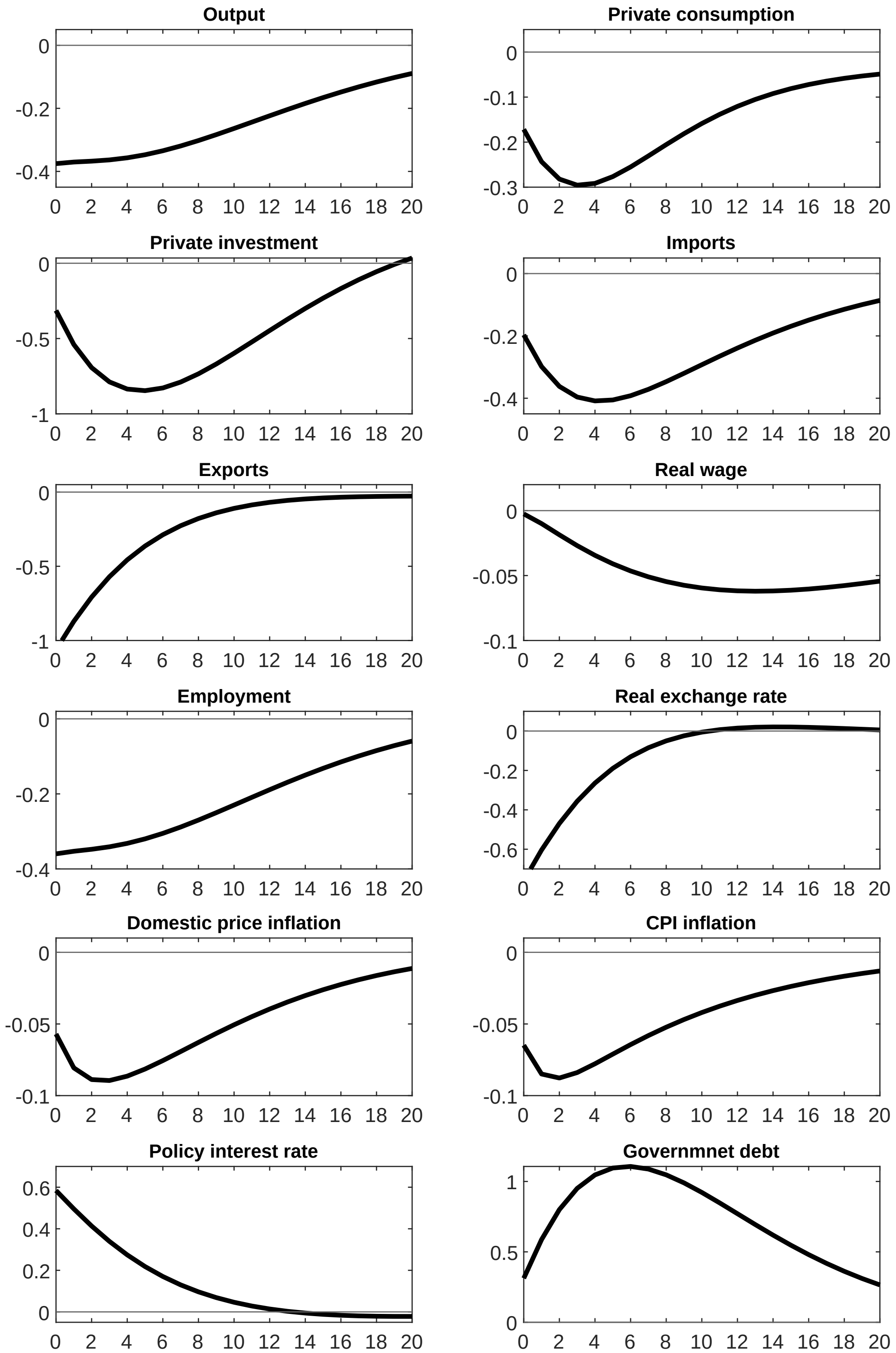
Figure 4.3 presents the response to a one standard deviation interest rate shock. The contractionary policy shock results in the standard response from model variables: a persistent decline across output, consumption, investment and labour, and a dip in inflation. Additionally, in the open economy setting, the appreciation of the domestic currency leads to expenditure-switching from domestic towards foreign goods. The appreciation in the real exchange rate more than offsets the drop in domestic price inflation, resulting in a contraction in exports. Imports also fall, but by less than domestic demand (on impact). The broad-based decline in aggregate demand results in cutback in employment and downward pressure on wages, which translates into lower pricing pressure (through the marginal cost channel). The demand response is aggravated by increased taxes and lower government spending (and transfers) in the face of a rising debt burden.

Figure 4.4 presents the response to a transitory technology shock. The technology shock triggers a decline in marginal cost, which causes domestic prices to fall. Domestic demand adjusts slowly to the increase in supply and, as such, both employment and nominal wages go down. However, the drop in price inflation counters the fall in nominal wages resulting in a slight increase in the real wage. The depreciation of the real exchange rate results in a deterioration in the terms of trade and a concomitant drop in imports and improvement in exports. The rise in import prices results in a smaller decline in CPI inflation relative to domestic prices.

A shock to the domestic price markup, presented in Figure 4.5, results in a significant increase in domestic price inflation. The concomitant interest rate response lead to a decline in private consumption and investment. The shock to aggregate demand is exacerbated by increased taxes and decreased government spending in the face of rising debt. The appreciation in the real exchange rate results in a drop in exports and improved imports, despite the drop in aggregate demand. The decline in aggregate demand results in a decline in hours worked (employment) and exerts downward pressure on real wages.

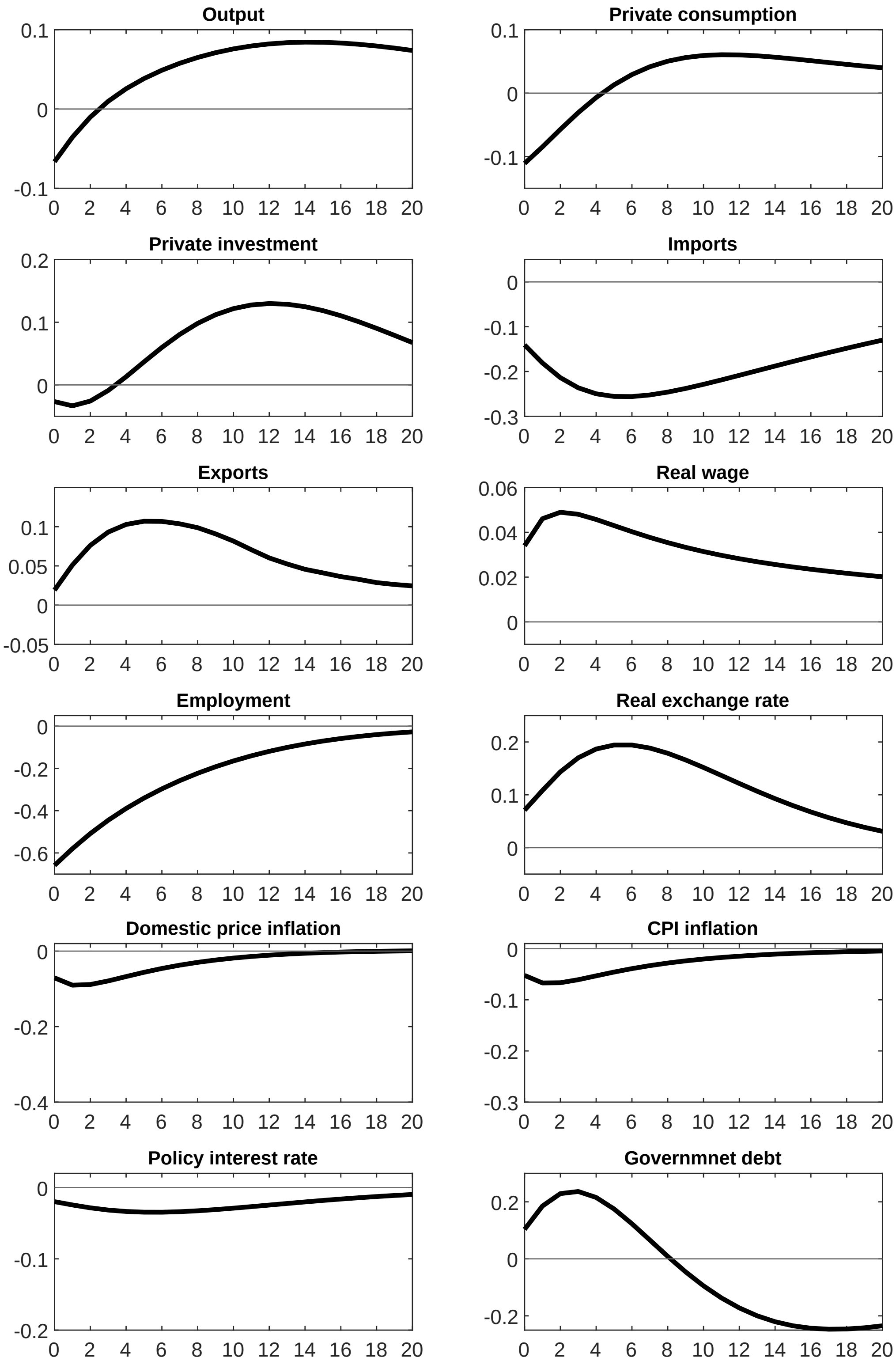
A shock to foreign demand (Figure 4.6), leads to a rise in foreign inflation and the foreign interest rate. The rise in foreign inflation leads to a depreciation in the real exchange rate for the domestic economy. The depreciation in the currency, combined with improved foreign demand conditions, lead to a rise in exports, supporting domestic output growth. The real depreciation also results in lower import demand. Higher inflation abroad reflects in higher import inflation, resulting in higher domestic price inflation and a concomitant tightening of monetary policy.

Figure 4.3: Monetary policy shock



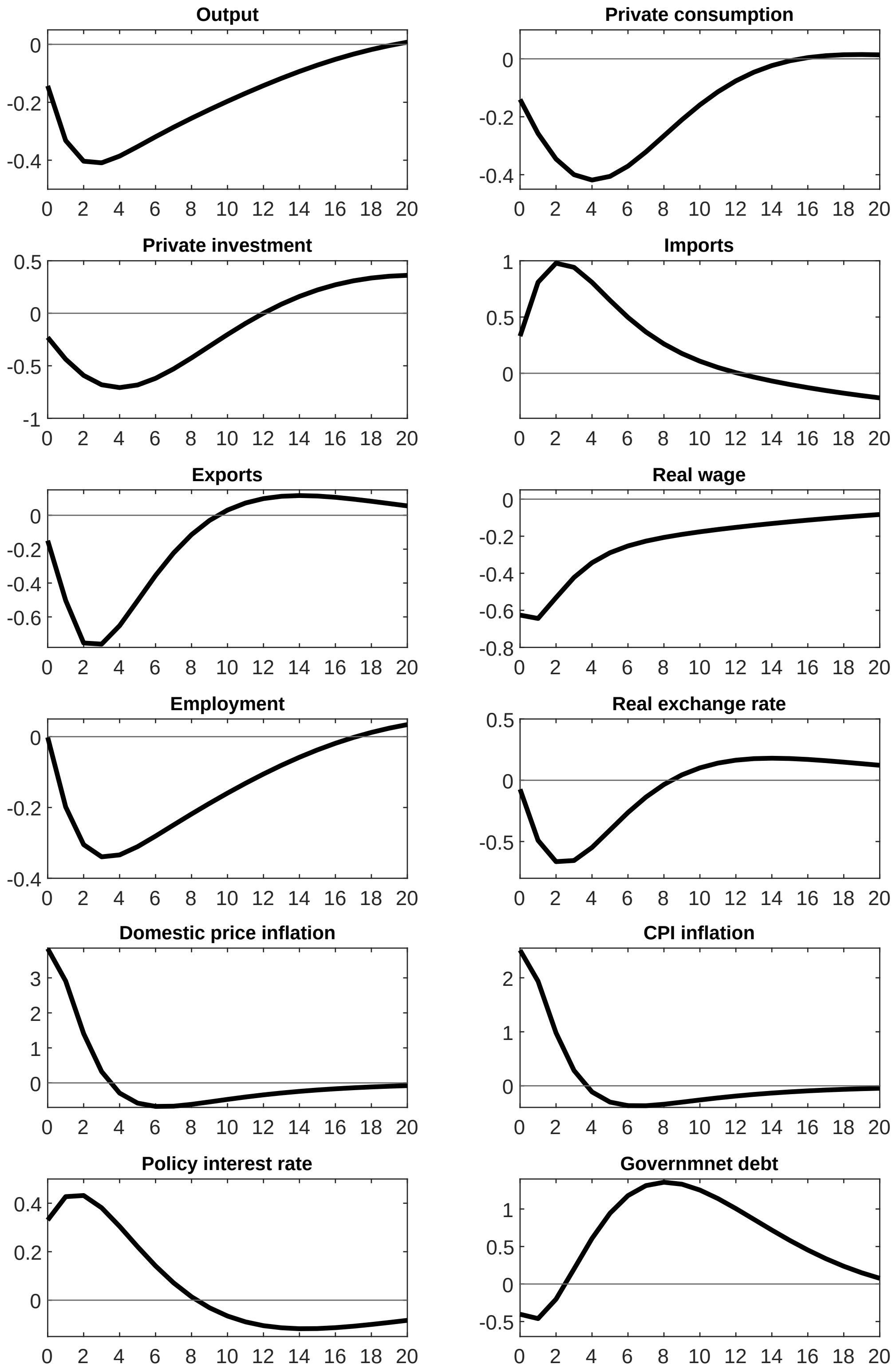
Note: All impulse responses are reported as percentage deviations from the non-stochastic steady state, except for inflation rates and the interest rate which are reported as annualised percentage-point deviations.

Figure 4.4: Transitory technology shock



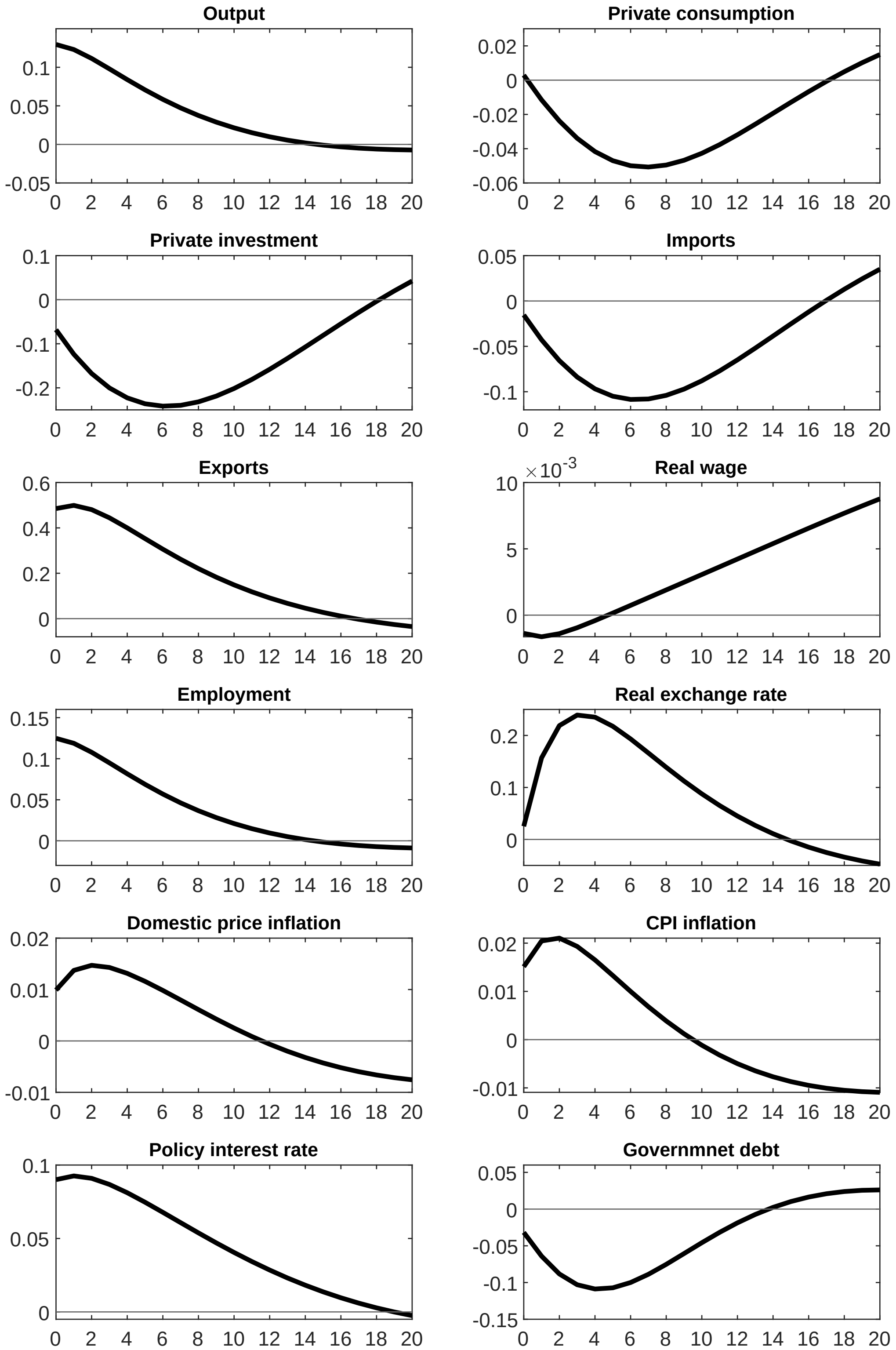
Note: All impulse responses are reported as percentage deviations from the non-stochastic steady state, except for inflation rates and the interest rate which are reported as annualised percentage-point deviations.

Figure 4.5: Domestic markup shock



Note: All impulse responses are reported as percentage deviations from the non-stochastic steady state, except for inflation rates and the interest rate which are reported as annualised percentage-point deviations.

Figure 4.6: Foreign output shock



Note: All impulse responses are reported as percentage deviations from the non-stochastic steady state, except for inflation rates and the interest rate which are reported as annualised percentage-point deviations.

4.5 The dynamic response to fiscal policy innovations

The previous section presented the estimated model and showed that it fit the data reasonably well and responded as expected in response to key structural shocks. This section will explore the response of the model to fiscal shocks. In particular, the response of model variables to different fiscal shocks will be investigated under different debt-financing arrangements. The first subsection investigates the dynamic response to fiscal policy innovations, while the second subsection calculates fiscal multipliers under different scenarios.

4.5.1 Impulse responses

Figures 4.7 to 4.11 plot the impulse responses following a temporary one standard deviation exogenous increase in each fiscal instrument. Each row investigates the responses of a the relevant endogenous variable under different specifications for the fiscal rules. The rules are adjusted by limiting a specific instrument or set of instruments' ability to respond to changing debt levels. That is, the debt feedback coefficients in the fiscal rules are altered. The first column in each figure represents the response of the variable in the model where all fiscal instruments respond to debt. In the second column, only transfers are allowed to respond. The third column gives the results when both government consumption spending and investment respond to debt, while the final column present the case where only tax rates are permitted to respond to debt. In general, as also shown in Leeper et al. (2010), the figures show that the effects of fiscal policy shocks depend crucially on the debt-financing arrangement.

Figure 4.7 shows the responses of output, private consumption, private investment and government debt following a one standard deviation shock to government consumption spending. As is standard in this type of model, an increase in government spending induces a negative wealth effect, leading to an increase in labour supply and hence output. Government spending crowds out private investment, as reflected in the dip in private investment, while the negative wealth effect leads to a drop in consumption. Furthermore, government consumption enters the aggregate consumption good as a substitute to private consumption, thereby exacerbating the negative consumption response. The duration of these effects depends crucially on the debt-financing arrangement embodied in the fiscal rule. When only transfers adjust to stabilise debt, the effects are long-lasting. When only spending variables adjust, output quickly returns to its steady state level as the subsequent decline in government consumption and investment spending in response to rising debt levels weighs on output growth. Under the assumption that only effective tax rates respond to deviations in debt, output returns to its steady state level within five years as tax rates respond to rising debt levels. The negative response of private consumption and investment is long-lasting as the increases in distortionary labour, consumption, and capital taxes weigh on private aggregates.

The response of model variables to a shock to public sector investment is qualitatively similar (see Figure 4.8). However, as public capital was shown to be a complement to private capital in composite capital good used in private production, the increased public investment expenditure and concomitant increase in public capital results in a slightly more muted (negative) private investment response. Additionally, the private consumption response turns positive after two years due to the reduction in government consumption expenditure in response to rising debt levels. Importantly, the output response following a shock to public sector investment is larger than the response following a shock to government consumption expenditure under all the alternative specifications. This suggests that public sector fixed investment is better suited to stimulating economic activity than current government expenditure.

Figure 4.7: Government spending shock

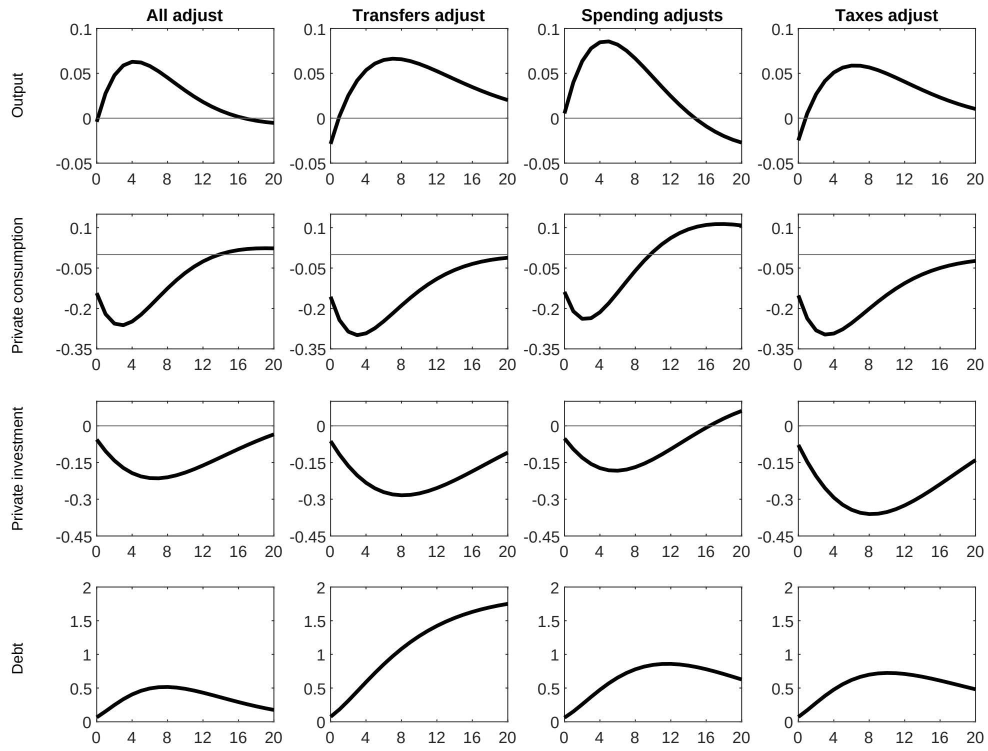


Figure 4.8: Government investment shock

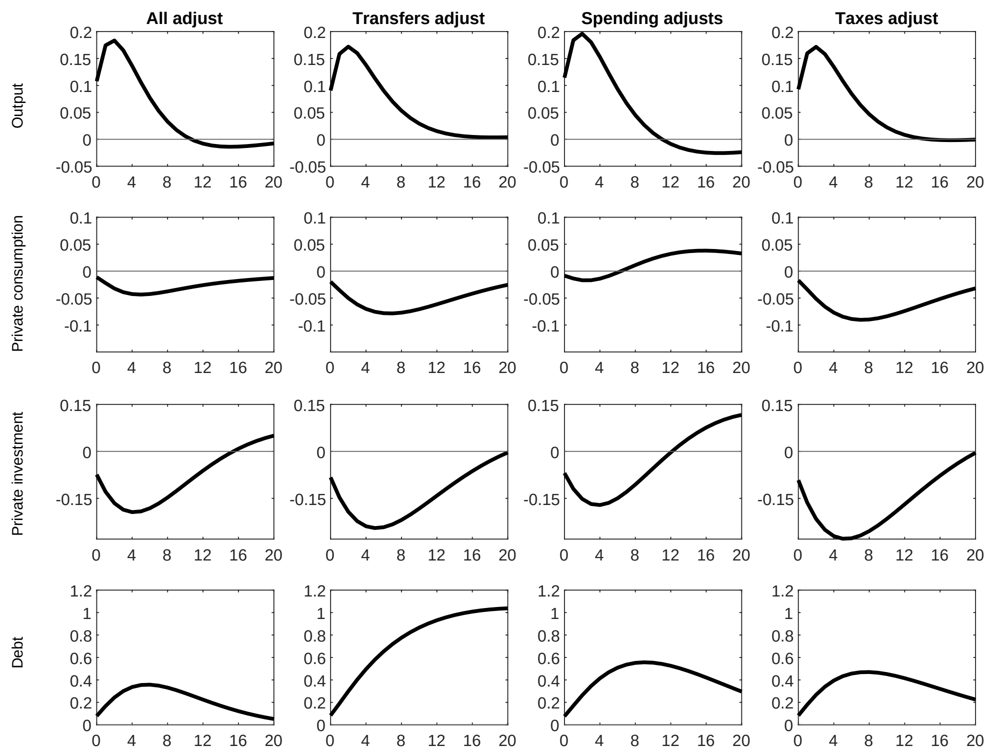


Figure 4.9: Labour tax shock

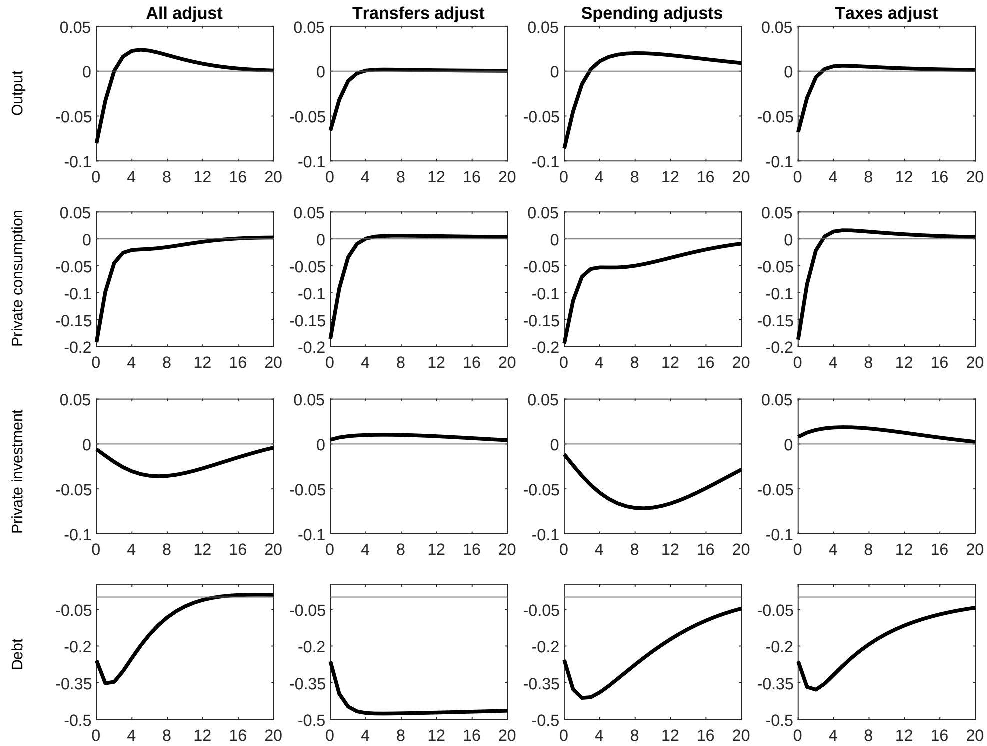


Figure 4.10: Capital tax shock

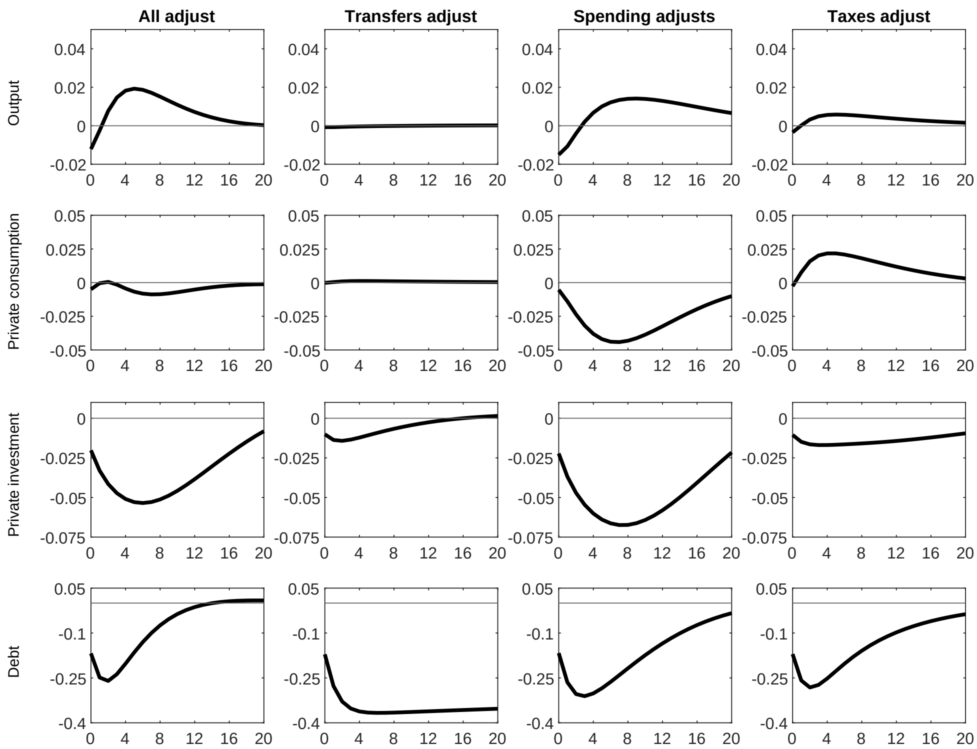
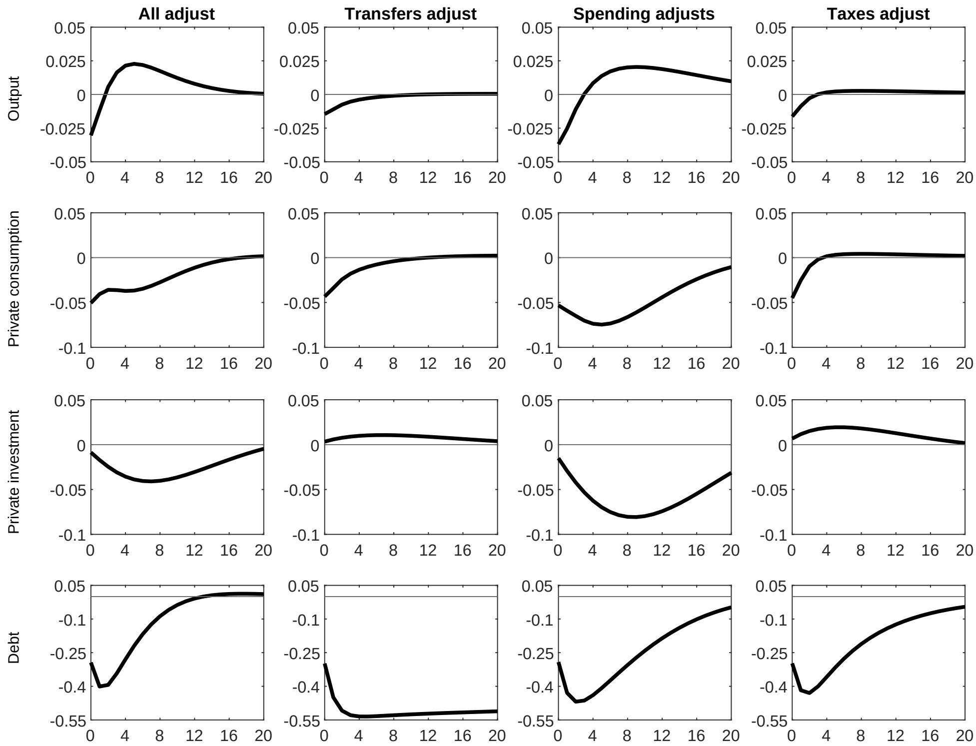


Figure 4.11: Consumption tax shock



Turning to tax shocks, Figure 4.9 reports the effect of a one standard deviation increase in the effective labour tax rate. The responses are broadly intuitive, with higher labour taxes inducing a negative labour supply response, which, in turn, reduces income and consumption. The reduction in labour supply also leads to a reduction in output. Once again, the duration of the effects depends crucially on the debt financing arrangement. It might be expected that investment will also fall since the return to capital drops as households reduce their labour supply. However, under certain financing arrangements the impact might be positive. For example, under the scenario where only taxes adjust to debt, the private investment response is (marginally) positive throughout. This is due to the decline in both consumption and capital tax rates in response to lower government debt levels.

Figure 4.10 presents the results for a one standard deviation shock to the capital tax rate. Standard theory suggests that an increase in capital taxes induces declines in private investment, labour supply, and output, while consumption rises as agents sacrifice investment for consumption (Leeper et al., 2010). However, in the current model these responses are not always apparent. As expected, the response of private investment is negative no matter what debt financing arrangement is in place. However, the output and consumption responses depend crucially on which fiscal instruments respond to debt. When all government spending variables adjust, the output response turns positive after about a year as government consumption and investment increase following the decline in government debt. When only taxes adjust, the consumption response is positive as labour and consumption taxes fall, resulting in an *expansion* in output.

Finally, the response to a shock to consumption taxes is qualitatively similar to those discussed above, although the consumption and investment responses are reversed. An increase in consumption taxes reduce output on impact as consumption declines. The response of private investment depends crucially on the financing arrangement. When only spending variables adjust, the negative wealth effect of the increase in government consumption spending crowds out the effect of increased government investment spending, with the response of both private consumption and investment more pronounced than under other financing arrangements. However, when only tax rates adjust, the drop in capital tax rates result in a positive response for private investment, while the decline in consumption taxes results in a less pronounced negative response from private consumption.

4.5.2 Fiscal multipliers

As in Chapter 3, the quantitative effects of fiscal policy shocks are summarised using present-value fiscal multipliers. Present value multipliers are calculated in a similar fashion to those presented in Chapter 3, i.e. as the ratio of the (discounted) *integral* of the output response to the *integral* of the government spending response. That is:

$$\text{Present-value multiplier at horizon } k = \frac{\sum_{j=0}^{k}(1+r)^{-j}y_{t+j}}{\sum_{j=0}^{k}(1+r)^{-j}f_{t+j}}\frac{1}{f/y} \tag{4.5.1}$$

where y_{t+j} is the response of GDP component at period j, f_{t+j} is the response of the fiscal variable at period j, and r is the average (model consistent) nominal policy interest rate over the sample. As before, the responses are scaled by f/y (the ratio of the fiscal variable to real GDP evaluated at the sample mean). For comparison with the results from Chapter 3, the tax response is measured as the response in total tax revenue (that is f is equal to labour, capital and consumption tax *revenue* when investigating the impact of unanticipated tax shocks). Present-value fiscal multipliers under the scenario when all fiscal variables respond to debt are presented in Table 4.4.

Table 4.4: Present-value multipliers: All instruments respond

Variable	Q1	Q4	Q8	Q20	∞
Government consumption multiplier					
$\frac{\Delta Y}{\Delta G}$	-0.04	0.19	0.21	0.20	0.20
$\frac{\Delta C}{\Delta G}$	-0.82	-0.72	-0.64	-0.55	-0.55
$\frac{\Delta I}{\Delta G}$	-0.07	-0.08	-0.10	-0.12	-0.11
Government investment multiplier					
$\frac{\Delta Y}{\Delta I_G}$	0.56	0.62	0.57	0.51	0.51
$\frac{\Delta C}{\Delta I_G}$	-0.04	-0.07	-0.09	-0.12	-0.12
$\frac{\Delta I}{\Delta I_G}$	-0.05	-0.07	-0.09	-0.09	-0.09
Labour tax multiplier					
$\frac{\Delta Y}{\Delta T^w}$	-0.42	-0.28	-0.13	-0.04	-0.04
$\frac{\Delta C}{\Delta T^w}$	-0.62	-0.75	-0.88	-0.91	-0.91
$\frac{\Delta I}{\Delta T^w}$	0.00	-0.03	-0.07	-0.10	-0.10
Capital tax multiplier					
$\frac{\Delta Y}{\Delta T^k}$	-0.15	0.10	0.36	0.49	0.49
$\frac{\Delta C}{\Delta T^k}$	-0.04	-0.04	-0.11	-0.17	-0.18
$\frac{\Delta I}{\Delta T^k}$	-0.03	-0.13	-0.22	-0.31	-0.31
Consumption tax multiplier					
$\frac{\Delta Y}{\Delta T^c}$	-0.19	-0.04	0.14	0.24	0.24
$\frac{\Delta C}{\Delta T^c}$	-0.19	-0.41	-0.60	-0.68	-0.68
$\frac{\Delta I}{\Delta T^c}$	-0.01	-0.05	-0.09	-0.13	-0.13

Output multipliers are positive for both government spending and investment shocks. Importantly, the positive output multipliers are smaller than one across the board, although the public sector investment multiplier is significantly larger than the spending multiplier. Government spending and investment shocks crowd out private consumption and investment, resulting in smaller multipliers than those recorded in Chapter 3. Consumption multipliers are negative following both a labour and consumption tax shock, while investment responds negatively to a capital tax shock. The positive output multipliers following a capital tax shock reflects the drop in tax rates and the expansion in public spending and investment in response to falling debt levels.

Present value multipliers under other financing arrangements broadly follow the intuition of the impulse response analysis above (details are presented in Tables C.2 and C.3). Shocks to government investment consistently produce larger and more persistent positive effects on output (in present value terms). In contrast, labour and consumption taxes are highly distortionary, resulting in relatively persistent declines in output and consumption.

4.5.3 Consumption multipliers and non-Ricardian households

As mentioned earlier, a key driver of positive output multipliers in response to government spending shocks in the empirical literature is the finding that consumption reacts positively to shocks to government consumption spending. However, the evidence does not universally support the idea that higher government spending raises private consumption. In fact, in the context of the current study, both the empirical exercise in Chapter 3 and the structural model in the current chapter does not point to positive consumption multipliers, despite the addition of rule-of-thumb consumers.

That being said, the estimated share of non-Ricardian households in the current model set-up is quite low. The question is whether a larger share of non-Ricardian household could generate positive consumption multipliers. Table 4.5 presents present-value output and consumption multipliers following a shock to government spending for different assumptions regarding the share of non-Ricardian households. [77]

Table 4.5: Present-value multipliers for different values of ω

	Q1	Q4	Q8	Q20	∞
$\omega = 0.233$ (baseline estimate)					
$\frac{\Delta Y}{\Delta G}$	-0.04	0.19	0.21	0.20	0.20
$\frac{\Delta C}{\Delta G}$	-0.82	-0.72	-0.64	-0.55	-0.55
$\omega = 0.50$					
$\frac{\Delta Y}{\Delta I_G}$	0.07	0.29	0.30	0.27	0.27
$\frac{\Delta C}{\Delta I_G}$	-0.574	-0.51	-0.49	-0.45	-0.45
$\omega = 0.75$					
$\frac{\Delta Y}{\Delta T^w}$	0.20	-0.42	0.41	0.35	0.34
$\frac{\Delta C}{\Delta T^w}$	-0.27	-0.28	-0.30	-0.34	-0.35
$\omega = 0.90$					
$\frac{\Delta Y}{\Delta T^k}$	0.29	0.51	0.49	0.40	0.38
$\frac{\Delta C}{\Delta T^k}$	-0.07	-0.11	-0.18	-0.28	-0.30

[77] The table presents results for the baseline model where all fiscal instruments respond to stabilise debt, but the results are qualitatively similar for other financing arrangements.

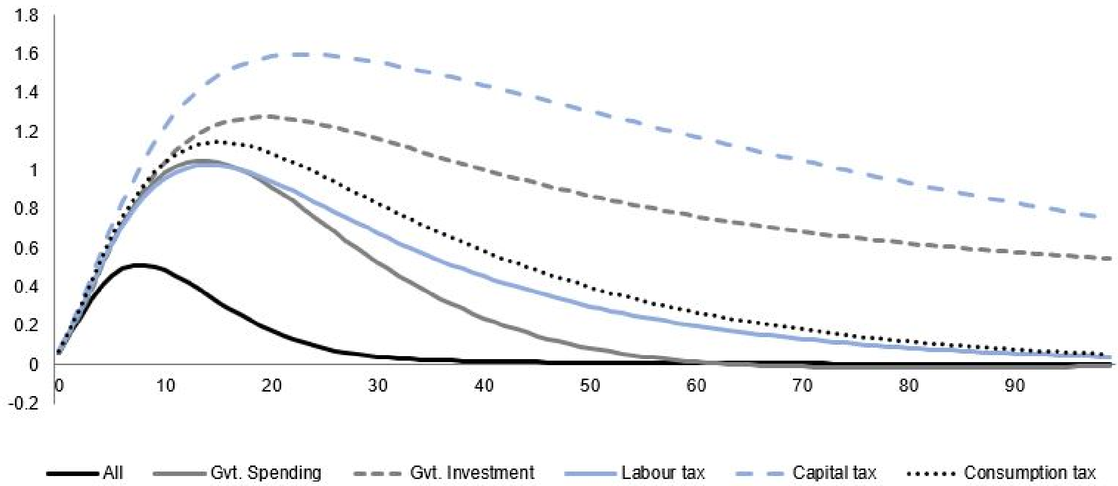
While the implied multipliers do increase with the share of non-Ricardian households, consumption multipliers never turn positive, while the output multipliers remain well below one. This finding is consistent with evidence for open economies (see, for example, Marco et al., 2006; Forni et al., 2009; Naitram et al., 2015; Sin, 2016). Additionally, the introduction of additional frictions in the model set-up in the form of labour and consumption taxes (which respond to debt), serves to dampen the effect of government spending increases.

4.5.4 Dynamics of debt financing

Another question that arises relates to the efficacy of the different fiscal instruments in restoring steady-state level debt following a fiscal policy innovation. Figure 4.12 plots the response of government debt to a one standard deviation innovation in government consumption spending.[78] Each line represents the impulse if only that specific fiscal instrument adjusts to changes in government debt.

It is clear that a spending shock results in a persistent deviation in debt from its steady state level, regardless of the financing method. Even in the case where all instruments respond collectively, it takes several years for debt to return to its steady state level. In terms of the individual fiscal instruments, the most effective consolidation tools appear to be government consumption spending, and labour and consumption taxes. In contrast, government investment spending and capital taxes appear to be ineffective at brining debt back to its steady state level, even over a longer time period. The long-lasting impact of fiscal policy innovations on debt is well-documented in the literature (see Leeper et al., 2010 for a particularly well-constructed contribution).

Figure 4.12: Debt financing dynamics



4.5.5 The role of automatic stabilisers

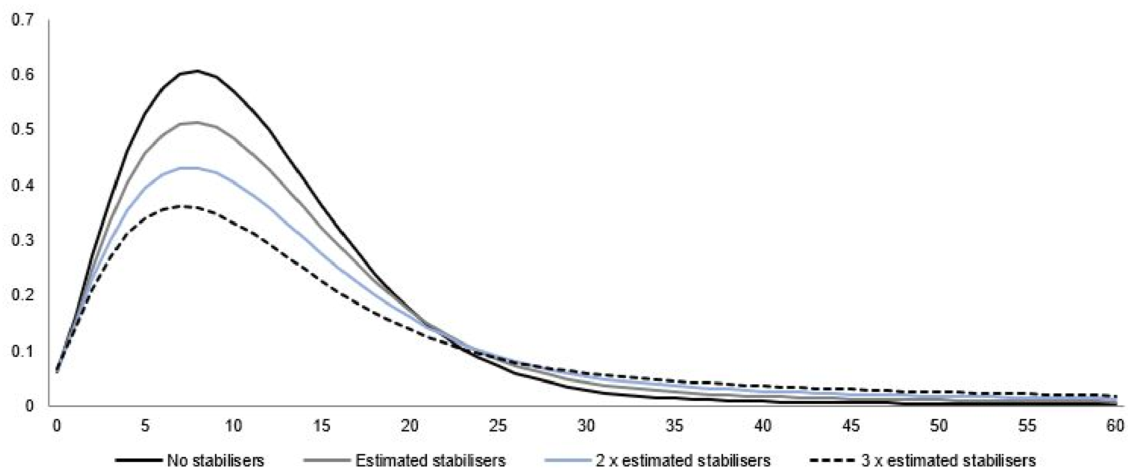
Assumptions regarding the role of automatic stabilisers also play an important role in debt dynamics. In the baseline results discussed above, the coefficients measuring the contemporaneous response of fiscal variables to output were set at their estimated values (as shown in Table C.1, Appendix C).

[78]The results are shown for a shock to government spending. While the relative magnitudes and duration differ according to the initial shocked fiscal variable, the general conclusions hold for other shocks.

Figure 4.13 presents government debt dynamics following a shock to government consumption spending and assuming all fiscal instruments adjust to stabilise debt. The figure shows results for four different assumptions regarding the automatic response of fiscal instruments to output fluctuations: no automatic response, estimated response, twice the estimated response, and three times the estimated response.

Stronger automatic responses reduce short-run fluctuations, as reflected in the more muted short-term response of debt to the spending shock. However, stronger automatic responses could impose other long-run costs. Higher government spending raises output, which, under the estimated fiscal rules, indices an increase in capital and labour taxes and a decline in transfers. This, in turn, lowers output. This dynamic is more pronounced under stronger automatic stabilisers. The decline in output over the longer term reduces tax revenues, resulting a slightly more persistent deviation from steady state debt (see Figure 4.13).

Figure 4.13: Role of automatic stabilisers in debt dynamics



4.6 Conclusion

In this chapter, an open-economy fiscal DSGE model for the South African economy was constructed. The model includes a detailed fiscal block, as well as several other characteristics that make estimation feasible.

The estimated model fits the data reasonably well and was used to simulate the effect of innovations to the different fiscal instruments on macroeconomic aggregates, including GDP, private consumption and investment. The results highlight the fact that the fiscal policy process is highly complex and that the impact of fiscal policy decisions on macroeconomic aggregates depends crucially on assumptions about which fiscal instruments adjust to stabilise debt.

Policy simulations indicate that government spending and investment multipliers are generally positive, albeit smaller than one. Multipliers are also generally smaller than the estimates presented in Chapter 3, consistent with the idea that spending multipliers are smaller in open-economy settings. Secondly, the estimates indicate that taxes are highly distortionary, with large negative multipliers for private consumption and investment. In contrast, the impact of tax shocks on output is highly ambiguous, with assumptions regarding which instruments adjust to debt and the size of automatic stabilisers playing an important role. Finally, a look at debt dynamics indicates that government consumption spending and, to a slightly lesser extent, labour and consumption taxes are the most effective instruments for stabilising debt after a fiscal shock. This again highlights the findings from Chapter 3: cuts in government consumption expenditure, combined with some measure of tax increases, present the most effective options when it comes to the need for fiscal consolidation.

That being said, conclusions about the effects of fiscal policy depend crucially on the nature of the underlying fiscal rules. As such, it is important for the researcher, and policy maker, to understand the different dynamics under different assumptions regarding the functional form of said rules.

This chapter provides some insight into how fiscal policy decisions affect the economy. While the underlying dynamics are complex, the rules are relatively simple and the model economy could be expanded to include even more realistic assumptions. These could include distinguishing between productive and unproductive government spending, detailed modelling of monetary policy behaviour, regime-switching fiscal policy, expanding the model to account for differing trends in fiscal variables, and introducing fiscal foresight in the open-economy setting.[79] Additionally, the analysis could be extended in order to consider optimal fiscal rules, as well as the differentiated impact of permanent versus temporary innovations to fiscal instruments.

[79] Jooste and Naraidoo (2017) incorporate an ad hoc measure of fiscal foresight in a calibrated, closed-economy DSGE model for South Africa.

Chapter 5

Conclusion

This research study was primarily motivated by the renewed interest in the effects of fiscal policy on general macroeconomic outcomes and macroeconomic stability since the 2008/09 Global Financial Crisis . The large-scale fiscal stimulus programmes implemented in the wake of the crisis ignited renewed interest in the possible long-term impact of persistent government budget deficits and the associated increase in public debt ratios, particularly in an environment of weak economic growth.

The debate surrounding the efficacy of fiscal policy, and the use of macroeconomic policy in general to stimulate demand, has reached fever pitch in South Africa. In an environment of anaemic growth and low business and consumer confidence, calls for expansionary monetary and fiscal policy have become more frequent and vociferous. While there is ample research on the effects of monetary policy on macroeconomic outcomes within the South African context, very little work has been done with respect to the transmission of fiscal policy decisions to broader outcomes.

Against this background, the research study aimed to provide insights into specific aspects of the transmission of fiscal policy decisions to broader economic outcomes in the South African context.

Chapter 2 investigated the behavioural responses of individual taxpayers to changing tax rates. In this regard, the elasticity of taxable income (ETI) is a key concept. The elasticity aims to capture all possible behavioural responses to changes in income taxation in a single measure, without the need to specify the nature of the adjustment processes involved. In the absence of any large tax reforms over the sample period in question, the phenomenon of 'bracket creep' was used to estimate the ETI for South Africa. The ETI is estimated at around 0.3, while the elasticity for broad income is estimated at closer to 0.2. These estimates lie close to the mid-point of estimates found in the literature. Additionally, it was found that behavioural responses are concentrated in higher-income groups as suggested by the higher elasticity estimate for the top 10% of income earners.

Important from a policy perspective is the conclusion that significant increases in the legislated marginal tax rate could trigger behavioural responses that might nullify any potential revenue gain. The ETI estimates were embedded in an optimal tax framework. The optimal tax results point to an optimal tax rate for the top 10% of income earners in line with a legislated marginal personal income tax rate of around 40%. This stands in contrast to the recently introduced legislated top marginal rate of 45%. The conclusions of the chapter are corroborated by the fact that the expected revenue gain from the implementation of the new top tax rate did not materialise. While automatic stabilisers also played a role, behavioural responses from high-income earners likely contributed its fair share.

As mentioned in Chapter 2, while the use of 'bracket creep' to identify the ETI is useful in the case where large tax reforms are unavailable, several caveats apply. The main drawback of the method is the fact that, because 'bracket creep' is not a legislated tax change, taxpayers may not be fully aware of the change and, therefore, might not respond fully. That being said, the analysis presented in Chapter 2 provides a solid starting point for further investigation into the behavioural response of taxpayers to changing tax rates.

Chapter 3 shifted the focus to the impact of fiscal policy decisions on macroeconomic aggregates, including GDP and its components. A key aim of the chapter was to estimate budgetary multipliers. The size of these budgetary multipliers has been heatedly debated in the international literature at both the theoretical and empirical level. While there was a renewed interest post-GFC in the impact of activist fiscal policy measures on macroeconomic outcomes, very little work has been done in the South African context. Chapter 3 contributes to the literature by estimating fiscal multipliers for South Africa using a variety of identification approaches, including the well-known recursive identification scheme, the Blanchard-Perotti approach, and sign restrictions.

The main findings show that the size of estimated budgetary multipliers is sensitive to identification strategy and modelling approach employed. That being said, in general the estimation results show that government spending multipliers are positive, although generally smaller than one. In contrast, tax multipliers are found to be large and distortionary.

Finally, the literature on fiscal multipliers has over the last decade explored the possibility that multipliers might differ depending on the state of the economy. To that end, Chapter 3 estimates state-dependent fiscal multipliers for South Africa using the approach employed by, among others, Auerbach and Gorodnichenko (2012b) and Auerbach and Gorodnichenko (2012a). Estimates show that both government spending and tax multipliers are larger during periods of slack, with long-term present-value multipliers doubling in size during recessionary states. The findings highlight the importance of taking the state of the economy into account when making policy decisions.

The estimated fiscal multipliers presented in Chapter 3, combined with insights from Chapter 2, suggest that fiscal consolidation is best served through policies aimed at reducing government spending rather than increased taxes. That being said, no distinction was made between the different effects of current government expenditure and public investment expenditure, and/or the effects of different tax measures.

In order to investigate the effects of shocks to disaggregated fiscal instruments, Chapter 4 specified and estimated an open-economy fiscal dynamic stochastic general equilibrium (DSGE) model for the South African economy which included a detailed fiscal block. The fiscal block included three government spending and three tax instruments.

Simulation results highlighted the fact that the fiscal policy process is highly complex and that the impact of fiscal policy decisions on macroeconomic aggregates depends crucially on assumptions about which fiscal instruments adjust to stabilise debt. That being said, policy simulation suggest that government spending and investment multipliers are generally positive, albeit smaller than one. Multipliers are also generally smaller than the estimates presented in Chapter 3, consistent with the finding in the literature that spending multipliers are smaller in open-economy settings.

Secondly, the simulations indicate that taxes are highly distortionary, with large negative multipliers for private consumption and investment. In contrast, the impact of tax shocks on output is highly ambiguous, with assumptions regarding which instruments adjust to debt and the size of automatic stabilisers playing an important role.

Finally, a look at debt dynamics indicate that government consumption spending and, to a slightly lesser extent, labour and consumption taxes are the most effective instruments for stabilising debt after a fiscal shock. This corroborates the findings from Chapter 3: cuts in government consumption expenditure, combined with some measure of tax increases, present the optimal fiscal policy mix when it comes to the need for fiscal consolidation. That being said, conclusions about the effect of fiscal policy decisions on broader macroeconomic outcomes depend crucially on the nature of the underlying fiscal rules.

The research study investigated several aspects relating to the effect of fiscal policy decisions on economic outcomes, including the impact on individual behaviour and broader macroeconomic aggregates, within the South African context. The broad conclusion is that fiscal policy decisions can have significant distortionary effects.

Unanticipated shocks to government consumption and investment spending have positive output effects, although estimated fiscal multipliers are smaller than one in most cases. This is partly due to the fact that government consumption and investment crowd out their private sector counterparts as households optimise over the expected future policy changes required to stabilise debt. Similarly, unanticipated shocks to tax policy can have large and distortionary effects.

The results highlight the fact that the fiscal policy process, and its interaction with economic outcomes, is highly complex. The impact of fiscal policy decisions on individual behaviour and macroeconomic aggregates depends crucially on the identifying assumptions used, the structure of the underlying model, the nature of the underlying fiscal rules, and assumptions about which fiscal instruments adjust to stabilise debt.

Despite the inherent complexity of the interaction between fiscal policy decisions and macroeconomic outcomes, the study provides valuable insight into the functioning of the South African economy and the research contributes meaningfully to the burgeoning fiscal policy literature in South Africa. It also provides a new tool for fiscal policy analysis in the form of an estimated open-economy DSGE model with detailed fiscal rules.

Finally, the study highlights several avenues for future research. These include further investigation into the empirical effects of disaggregated fiscal variables on economic outcomes, investigating the differentiated impact of productive and unproductive government spending, including government "production" in the structural model (i.e. public sector labour and wages), the detailed modelling of the interaction between monetary and fiscal policy, further investigation of state-dependent and/or regime-switching fiscal policy, and the inclusion of fiscal foresight and/or different expectations formation processes in both the empirical and theoretical models.

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Appendix A

The Elasticity of Taxable Income

A.1 Construction of income variables

Table A.1 details the construction of the gross and taxable income variables used in the regression analysis.

Table A.1: Construction of income variables

	Item	SARS code	Notes
	Local interest	4201	Local interest earned
+	Other gains	42*	Local dividends; rental profits/losses; income from building societies; income from fixed period shares and deposits; royalties; foreign investment income (interest, dividends); gambling gains/losses
−	Other losses	42*	
=	*Investment income (excl. capital gains)*		
+	Business profits	01-34*	Profits/losses from unincorporated businesses or trades
−	Business losses	01-34*	
=	*Business income*		
+	Normal income	36*	Local and foreign labour and pension income
+	Allowances	37*	
+	Fringe benefits	38*	
+	Lump sum income	39*	Local and foreign lump-sum income, including special remuneration and pension/ provident fund lump-sums
=	*Labour income*		
=	*Gross/broad income*		All incomes received by the individual
−	Deductions	40*	E.g., pension, provident or medical fund contributions, exempted portion of interest income, other exemptions
−	Exemptions	36-39*, 42*	
=	*Taxable income*		Taxable income used to determine the normal tax due (before any rebates and tax credits)

*Asterisks refer to the subset of items under the respective SARS Code that not mentioned separately in the table.

A.2 First stage regression results

Table A.2 shows selected results for the first stage regression of the endogenous variable on the instrument (and other exogenous variables), given by

$$\log[(1-T_2')/(1-T_1')] = \log[(1-T_p')/(1-T_1')] + \theta_1 \log z_1 + \theta_2 f(taxinc_1) + \sum_{i=1}^{10} \theta_{3i} SPLINE_i(z_1) + \sum_j \theta_{4j} YEAR_j + \gamma item + \epsilon$$

with columns corresponding to those in Table 2.4 in the main text.

Table A.2: First stage regression results

	Taxable Income				Broad Income			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Instrument	0.612***	0.529***	0.527***	0.533***	0.610***	0.531***	0.530***	0.532***
$\left(\log[(1-T_p')/(1-T_1')]\right)$	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]
Observations	6 016 788	6 016 788	6 016 788	6 016 788	6 016 788	6 016 788	6 016 788	6 016 788
Adjusted R^2	0.074	0.108	0.117	0.153	0.073	0.107	0.114	0.139
F-statistic	99 214***	72 088***	71 084***	52 147***	98 472***	70 722***	68 894***	44 216***

*, **, *** reflect significance at the 5%, 1% and 0.1% levels respectively. Regressions weighted by income. All regressions include dummy variables for each base year.

The first stage regression is very strong, suggesting instrument relevance and that a weak-instrument problem is not likely.

A.3 Censored sample results

Following Gruber and Saez (2002), the change in log income is censored at five so that the approximately 3000 observations who report changes in income ratios across the two years of more than 150 or less than 1/150 are censored. This avoids the influence of large once off increases/decreases in income or job shifting. The results are not very sensitive to this restriction. Table A.1 gives the estimated elasticities (standard errors in parentheses) for both the uncensored sample and censored sample for the different sets of control variables under investigation with columns corresponding to those in Table 2.4 in the main text.

Table A.3: Uncensored vs censored elasticity estimates

	Taxable Income				Broad Income			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$e^c_{uncensored}$	-1.820***	0.304***	0.262***	0.314***	1.764***	0.167***	0.139***	0.235***
	[0.053]	[0.038]	[0.019]	[0.059]	[0.048]	[0.034]	[0.018]	[0.055]
$e^c_{censored}$	-1.778***	0.313***	0.271***	0.308***	1.740***	0.172***	0.144***	0.231***
	[0.053]	[0.038]	[0.018]	[0.060]	[0.048]	[0.034]	[0.018]	[0.055]

Estimates of 2SLS regressions. *, **, *** reflect significance at the 5%, 1% and 0.1% levels respectively. Regressions weighted by income. All regressions include dummy variables for each base year.

A.4 Calculating the effective consumption tax rate

Ideally, one would need to measure the tax share of the consumption basket of high-earning households. However, due to data restrictions this is not possible in practice. An approximation of the effective rate of consumption taxes is used. Data on both private consumption expenditure and government revenue from domestic taxes on goods and services were obtained from the South African Reserve Bank's (SARB) Quarterly Bulletin. Data on government tax revenue contained in the Quarterly Bulletin is in turn based on the Statement of the National Revenue, Expenditure and Borrowing as published by National Treasury.

Table A.4: Effective consumption tax rate

	2008	2009	2010	2011	2012	Average
Private consumption expenditure (current prices, Rbn)	R1 421.795	R1 492.269	R1 621.836	R1 801.091	R1 983.604	R 1 664.119
Domestic taxes on goods and services (current prices, Rbn)	R197.840	R201.141	R233.626	R266.316	R286.694	R237.123
Effective consumption tax rate	13.9%	13.5%	14.4%	14.8%	14.5%	14.2%

Appendix B

Empirical estimates of fiscal multipliers for South Africa

B.1 Variable definitions and sources

Table B.1: Variable definitions and sources

Variable	Description	Source
Real government spending	Sum of government consumption expenditure and public sector investment	South African Reserve Bank
Total tax revenue	Sum of personal income tax, corporate income tax, tax on goods and services, and other direct and indirect taxes	
Private consumption expenditure	Real private consumer spending	
Private fixed investment	Real private fixed investment outlays	
Repo rate	Main repurchase rate	
GDP deflator		
CPI index	Headline CPI index for all urban areas	Statistics South Africa

B.2 Elasticity of tax revenue with respect to output

The elasticity of tax revenue to output, a_{ty}, is constructed through a weighted sum of the elasticities of the different tax instruments with respect to output.

The elasticity of each tax instrument with respect to output can be calculated either directly or indirectly (see Du Plessis et al. (2007)). Direct estimation involves calculating the sensitivity of the i^{th} tax component to output. The elasticity is estimated from an unrestricted VAR with the i^{th} tax component and output as the endogenous variables, using a lag order of four quarters. The following equation in the VAR, with the i^{th} tax component as dependent variable, is used to calculate the elasticity:

$$T_t^i = \mu + \sum_{k=1}^{4} \beta_k Y_{t-k} + \sum_{k=1}^{4} \gamma_k T_{t-k}^i + \epsilon_t$$

where the elasticity is then calculated as:

$$a_{t_iy} = \frac{\sum_{k=1}^{4} \beta_k}{1 - \sum_{k=1}^{4} \gamma_k}$$

However, where possible, it is more prudent to calculate the elasticity of the i^{th} tax category with respect to output indirectly, that is, as the product of two elasticities: the elasticity of the i^{th} tax category with respect to the relevant tax base ($\eta_i^{t,tb}$) and the elasticity of that tax base w.r.t. output ($\eta_i^{tb,y}$):

$$a_{t_iy} = \eta_i^{t,tb} \eta_i^{tb,y}$$

where $\eta_i^{t,tb}$ and $\eta_i^{tb,y}$ are each estimated from unrestricted VARs.

Data on personal income taxes (PIT), corporate income taxes (CIT), value added tax (VAT), and other indirect taxes sourced from the SARB Quarterly Bulletin, and are used together with real output to calculate the relevant elasticities. Fiscal series are seasonally adjusted and deflated using GDP deflator.

Table B.2: Exogenous elasticities with respect to real GDP

	Elasticity of tax item to tax base ($\eta_i^{t,tb}$)	Elasticity of tax base to output ($\eta_i^{tb,y}$)	Elasticity of tax item to output (a_{t_iy})	Share in total taxes (T_i/T)
PIT	1.58	0.87	1.37	0.32
CIT	1.17	0.96	1.12	0.23
VAT	1.31	1.20	1.58	0.20
Other indirect	-	-	1.05	0.25
Direct taxes			1.26	0.55
Indirect taxes			1.28	0.45
Total tax			1.27	

The indirect method is followed for estimating the elasticity of PIT, CIT and VAT with respect to output, with total compensation of employees, gross operating surplus and consumer spending serving as the respective tax bases. For indirect taxes excluding VAT, the direct method is used. Table B.2 provides details of the estimated elasticities. The aggregate elasticity of tax revenue with respect to output is calculated as the weighted sum of the individual elasticities. As such, $a_{ty} = 1.27$.

B.3 Elasticity of tax revenue with respect to private consumption and investment

Estimates for the elasticity of total taxes with respect to private consumption and investment are calculated in a similar fashion to the output elasticity described above and are provided in Table B.3.

Table B.3: Exogenous elasticities with respect to private consumption and investment

	Elasticity of tax base to private consumption ($\eta_i^{tb,C}$)	Elasticity of tax base to private investment ($\eta_I^{tb,I}$)	Elasticity of tax item to private consumption (a_{t_iC})	Elasticity of tax item to private investment (a_{t_iI})
PIT	0.68	0.59	1.07	0.94
CIT	0.76	0.26	0.88	0.31
VAT	1.31	0.64	1.31	0.84
Other indirect	-	-	0.82	0.70
Direct taxes			0.99	0.68
Indirect taxes			1.03	0.76
Total tax			1.01	0.71

B.4 Alternative SVAR specifications

B.4.1 Extended baseline VAR

The first set of alternative SVAR models extend the baseline VAR with an output component, either private consumption or investment, placed third in the system. Under the BP identification approach, the system can be written as:

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ -a_{yg} & 1 & 0 & -a_{yt} \\ -a_{y^ig} & -a_{y^iy} & 1 & -a_{y^it} \\ 0 & -1.27 & -a_{ty^i} & 1 \end{pmatrix} \begin{bmatrix} \eta_t^g \\ \eta_t^y \\ \eta_t^{y^i} \\ \eta_t^t \end{bmatrix} = \begin{pmatrix} b_{gg} & 0 & 0 & 0 \\ 0 & b_{yy} & 0 & 0 \\ 0 & 0 & b_{y^iy^i} & 0 \\ b_{tg} & 0 & 0 & b_{tt} \end{pmatrix} \begin{bmatrix} \varepsilon_t^g \\ \varepsilon_t^y \\ \varepsilon_t^{y^i} \\ \varepsilon_t^t \end{bmatrix} \tag{B.4.1}$$

where y^i is the output component under consideration, either private consumption or private investment. The elasticity estimates in Table B.3 are used to calibrate a_{ty^i} in B.4.1. For example, in the case of consumption, the system becomes:

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ -a_{yg} & 1 & 0 & -a_{yt} \\ -a_{y^ig} & -a_{y^iy} & 1 & -a_{y^it} \\ 0 & -1.27 & -1.01 & 1 \end{pmatrix} \begin{bmatrix} \eta_t^g \\ \eta_t^y \\ \eta_t^{y^i} \\ \eta_t^t \end{bmatrix} = \begin{pmatrix} b_{gg} & 0 & 0 & 0 \\ 0 & b_{yy} & 0 & 0 \\ 0 & 0 & b_{y^iy^i} & 0 \\ b_{tg} & 0 & 0 & b_{tt} \end{pmatrix} \begin{bmatrix} \varepsilon_t^g \\ \varepsilon_t^y \\ \varepsilon_t^{y^i} \\ \varepsilon_t^t \end{bmatrix} \tag{B.4.2}$$

B.4.2 Extended monetary policy VAR

The second set of alternative SVAR models extend the five-variable monetary policy VAR with an output component, either private consumption or investment, again placed third in the system. Under the BP identification approach, the system can be written as:

$$\begin{pmatrix} 1 & 0 & 0 & 0.79 & 0 & 0 \\ -a_{yg} & 0 & 1 & 0 & -a_{yt} & 0 \\ -a_{y^ig} & -a_{y^iy} & 1 & 0 & -a_{y^it} & 0 \\ -a_{\pi g} & -a_{\pi y} & -a_{\pi y^i} & 1 & -a_{\pi t} & 0 & 0 \\ 0 & -1.27 & -a_{ty^i} & -0.19 & 1 & 0 \\ -a_{rg} & -a_{ry} & -a_{ry^i} & -a_{r\pi} & -a_{rt} & 1 \end{pmatrix} \begin{bmatrix} \eta_t^g \\ \eta_t^y \\ \eta_t^{y^i} \\ \eta_t^\pi \\ \eta_t^t \\ \eta_t^r \end{bmatrix} = \begin{pmatrix} b_{gg} & 0 & 0 & 0 & 0 & 0 \\ 0 & b_{yy} & 0 & 0 & 0 & 0 \\ 0 & 0 & b_{y^iy^i} & 0 & 0 & 0 \\ 0 & 0 & 0 & b_{\pi\pi} & 0 & 0 \\ b_{tg} & 0 & 0 & 0 & b_{tt} & 0 \\ 0 & 0 & 0 & 0 & 0 & b_{rr} \end{pmatrix} \begin{bmatrix} \varepsilon_t^g \\ \varepsilon_t^y \\ \varepsilon_t^{y^i} \\ \varepsilon_t^\pi \\ \varepsilon_t^t \\ \varepsilon_t^r \end{bmatrix} \tag{B.4.3}$$

where y^i is the output component under consideration, either private consumption or private investment. The elasticity estimates in Table B.3 are used to calibrate a_{ty^i} in B.4.3. For example, in the case of consumption, the system becomes:

$$\begin{pmatrix} 1 & 0 & 0 & 0.79 & 0 & 0 \\ -a_{yg} & 0 & 1 & 0 & -a_{yt} & 0 \\ -a_{y^ig} & -a_{y^iy} & 1 & 0 & -a_{y^it} & 0 \\ -a_{\pi g} & -a_{\pi y} & -a_{\pi y^i} & 1 & -a_{\pi t} & 0 & 0 \\ 0 & -1.27 & -1.01 & -0.19 & 1 & 0 \\ -a_{rg} & -a_{ry} & -a_{ry^i} & -a_{r\pi} & -a_{rt} & 1 \end{pmatrix} \begin{bmatrix} \eta_t^g \\ \eta_t^y \\ \eta_t^{y^i} \\ \eta_t^\pi \\ \eta_t^t \\ \eta_t^r \end{bmatrix} = \begin{pmatrix} b_{gg} & 0 & 0 & 0 & 0 & 0 \\ 0 & b_{yy} & 0 & 0 & 0 & 0 \\ 0 & 0 & b_{y^iy^i} & 0 & 0 & 0 \\ 0 & 0 & 0 & b_{\pi\pi} & 0 & 0 \\ b_{tg} & 0 & 0 & 0 & b_{tt} & 0 \\ 0 & 0 & 0 & 0 & 0 & b_{rr} \end{pmatrix} \begin{bmatrix} \varepsilon_t^g \\ \varepsilon_t^y \\ \varepsilon_t^{y^i} \\ \varepsilon_t^\pi \\ \varepsilon_t^t \\ \varepsilon_t^r \end{bmatrix} \tag{B.4.4}$$

B.4.3 Present value multipliers for the extended monetary policy VAR

Table B.4 presents present-value multipliers based on the extended five- and six-variable monetary policy VARs.

Table B.4: Present-value multipliers based on monetary policy VAR

	Q1	Q4	Q8	Q12	Q20
Government spending multiplier					
Output					
Recursive	0.08	0.29	0.19	0.07	-0.10
Blanchard-Perotti	0.08	0.26	0.17	0.06	-0.11
Sign restriction	0.23	0.41	0.23	0.04	-0.24
Private consumption					
Recursive	0.09	0.05	-0.11	-0.22	-0.33
Blanchard-Perotti	0.08	-0.01	-0.14	-0.22	-0.32
Sign restriction	0.33	0.30	0.16	0.05	-0.08
Private investment					
Recursive	-0.04	-0.05	-0.13	-0.19	-0.26
Blanchard-Perotti	-0.06	-0.07	-0.13	-0.18	-0.24
Sign restriction	0.09	0.16	0.13	0.08	0.02
Tax multiplier					
Output					
Recursive	0.00	0.03	-0.03	-0.09	-0.15
Blanchard-Perotti	-0.15	-0.37	-0.65	-0.88	-1.14
Sign restriction	-0.18	-0.61	-1.56	-2.60	-4.25
Private consumption					
Recursive	0.00	0.02	-0.07	-0.14	-0.19
Blanchard-Perotti	-0.21	-0.56	-1.04	-1.46	-1.92
Sign restriction	-0.03	-0.05	-0.33	-0.61	-0.92
Private investment					
Recursive	0.00	-0.16	-0.31	-0.41	-0.47
Blanchard-Perotti	-0.33	-1.13	-2.21	-3.24	-4.39
Sign restriction	-0.04	-0.19	-0.41	-0.60	-0.78

Note: Output multiplies based on five-variable monetary policy VAR. Consumption and investment multipliers based on a six-variable VAR with consumption/investment ordered third.

B.5 Selected multiplier studies

Table B.5: Government spending multipliers from selected studies

Study	Region	Identification	Implied multiplier
Developed economies			
Barro (1981), Hall (1986), Hall (2009), Barro and Redlick (2011)	US	Military spending as instrument for government spending	0.6 - 1
Rotemberg and Woodford (1992)	US	Residuals from regression of military spending on own lags	1.25
Ramey and Shapiro (1998), Edelberg et al. (1999), Burnside et al. (2004)	US	Ramey-Shapiro military build-up dates	0.6 - 1.2
Blanchard and Perotti (2002)	US	SVAR with Cholesky decomposition	0.9 - 1.3
Perotti (2005)	US	SVAR with contemporaneous restrictions	0.3-1.4
	Germany		0.3
	UK		-0.6 - 0.5
Giordano et al. (2007)	Italy	SVAR with contemporaneous restrictions	1.2 - 1.7
Burriel et al. (2010)	Euro area	SVAR with contemporaneous restrictions	0.9
Mountford and Uhlig (2009)	US	Sign-restricted SVAR	0.65
Cogan et al. (2010)	US	Estimated Smets-Wouter model	0.64
Fisher and Peters (2010)	US	VAR using excess stock returns of military contractors	1.5
Jörn et al. (2010)	Germany	Disaggregated SVAR with contemporaneous restrictions	0.6 - 1.3
Ramey (2011a,b)	US	VAR using shocks to expected present value of of government spending caused by military events	0.6 - 1.2
Auerbach and Gorodnichenko (2012b)	US	SVAR that controls for forecast, Ramey-type news (regime switching)	Expansion: -0.3 - 0.8
			Recession: 1 - 3.6
de Castro and FernÃąndez (2013)	Spain	SVAR with contemporaneous restrictions	0.5 - 0.9
Owyang et al. (2013)	US	Defense spending news	0.8
	Canada		0.4 - 1.6
Parkyn and Vehbi (2014)	New Zealand	SVAR with contemporaneous restrictions and debt feedback	-0.1 - 0.4
Caldara and Kamps (2017)	US	SVAR with contemporaneous restrictions, sign restrictions, proxy-VAR	0.9 - 1.7
Developing economies			
Mirdala (2009)	European transition economies	SVAR with contemporaneous restrictions, long-run restrictions	positive
Lozano and Rodríguez (2011)	Colombia	SVAR with contemporaneous restrictions	1.2
Ravnik and Zilic (2011)	Croatia	SVAR with contemporaneous restrictions	negative
Guy and Belgrave (2012)	Several Caribbean countries	SVAR with contemporaneous restrictions	0.1 - 0.2
Jooste et al. (2013)	South Africa	VECM, time-varying parameter VAR, calibrated DSGE	> 1
Gnip (2014)	Croatia	SVAR with contemporaneous restrictions	0.33 (peak)
		Regime switching model	Expansion: 0.6 Recession: 2.2
IMF (2018)	19 Latin American countries	Local Projection Method with forecast errors	0.2
Alichi et al. (2019)	Several small states (IMF and World Bank definitions)	Local Projection Method with forecast errors	0.3 - 0.4

Table B.6: Tax multipliers from selected studies

Study	Region	Identification	Implied multiplier
Developed economies			
Blanchard and Perotti (2002)	US	Assumed output elasticity in SVAR	-0.5 to -1.7
Perotti (2005)	US	SVAR with contemporaneous restrictions	-1.4
	Germany		-0.05 - 0.3
	UK		-0.2 - 0.7
Mountford and Uhlig (2009)	US	Sign-restricted SVAR	-5
Burriel et al. (2010)	Euro area	SVAR with contemporaneous restrictions	-0.5
Romer and Romer (2010)	US	Narrative approach	-3
Barro and Redlick (2011)	US	Average marginal tax rates	-1.1
Favero and Giavazzi (2012)	US	Romer and Romer narrative series embedded in SVAR	-0.5
Mertens and Ravn (2014)	US	Proxy-SVAR using Romer and Romer series	-3
Caldara and Kamps (2017)	US	SVAR using outside elasticities	-0.65
Developing economies			
Mirdala (2009)	European transition economies	SVAR with contemporaneous restrictions, long-run restrictions	no effect, positive in some cases
Lozano and Rodríguez (2011)	Colombia	SVAR with contemporaneous restrictions	positive
Ravnik and Zilic (2011)	Croatia	SVAR with contemporaneous restrictions	positive
Guy and Belgrave (2012)	Several Caribbean countries	SVAR with contemporaneous restrictions	positive
Jooste et al. (2013)	South Africa	VECM, time-varying parameter VAR, calibrated DSGE	large and negative
Gnip (2014)	Croatia	SVAR with contemporaneous restrictions	-0.03 (impact)
		Regime switching model	Expansion: -0.02 Recession: 0.4
IMF (2018)	19 Latin American countries	Local Projection Method with forecast errors	-0.5 (average)
Alichi et al. (2019)	Several small states (IMF and World Bank definitions)	DSGE model	-0.4

Appendix C

A medium-sized, open-economy, fiscal DSGE model of South Africa

C.1 The log-linearised model

C.1.1 Transformation of variables

Following Christoffel et al. (2008) and Adolfson et al. (2007), among others, the model's structural relationships are cast into stationary form. This is done for two reasons: First, because it is assumed that underlying productivity growth follows a unit-root process, all real variables, with the exception hours worked, have a common real stochastic trend. Second, since the main aim of monetary policy is to stabilise inflation as opposed to the price level, nominal variables share a common nominal stochastic trend. In order to cast the model into stationary form, all real variables that share a common stochastic trend are scaled with the level of productivity, z_t, while all nominal variables are scaled by the price level of the consumption good, $P_{C,t}$. For notational simplicity, stationary variables are denoted by lower-case letters as opposed to the upper-case letters employed the discussion in Chapter 4. For example, $y_t = Y_t/z_t$ denotes the stationary level of aggregate output, while $p_{I,t} = P_{I,t}/P_{C,t}$ represents the relative price of the investment good.

That being said, there are a few exceptions. First, the nominal wage rate is assumed to grow in line with productivity and, as such, it needs to be scaled by both the price level, $P_{C,t}$, and the productivity level, z_t, in order to become stationary, i.e. $w_t = W_t/(z_t P_{C,t})$. Second, given that the model's endogenous state variables, such as the capital stock, are predetermined in a given period t, they they need to be scaled by the *lagged* value of productivity, that is, $k_t = K_t/z_{t-1}$. Third, following Christoffel et al. (2008), the marginal utility of consumption needs to be scaled *up* with the level of productivity to become stationary ($\lambda_t = z_t \Lambda_t$). Finally, foreign variables are scaled with the real foreign productivity trend, denoted by z_t^*. Furthermore, it is assumed that z_t and z_t^* share the same stochastic trend.

The following sections present the log-linearised equations characterising the model.

C.1.2 Households

Since all households make identical decisions in equilibrium, the household-specific indices i and j can be dropped. However, superscripts are used to distinguish between Ricardian (R) and non-Ricardian (NR) household variables.

Ricardian households

The households' choice of allocations

Applying the transformation detailed above to the households' first-order conditions (4.3.8) to (4.3.13) yields the following equivalent stationary conditions:

$$\lambda_t = \alpha_G^{\frac{1}{\nu_G}} \varepsilon_t^c \frac{\left(\tilde{c}_t^R - \kappa g_{z,t}^{-1} \tilde{c}_{t-1}^R\right)^{-1}}{1+\tau_t^c} \left(\frac{\tilde{c}_t^R}{c_t^R}\right)^{\frac{1}{\nu_G}} \tag{C.1.1}$$

$$p_{I,t} = Q_t \varepsilon_t^i \left(1 - \Gamma_I\left(g_{z,t} i_t^R / i_{t-1}^R\right) - \Gamma_I'\left(g_{z,t} i_t^R / i_{t-1}^R\right) g_{z,t} \frac{i_t^R}{i_{t-1}^R}\right) + \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t} Q_{t+1} \varepsilon_{t+1}^i \Gamma_I'\left(g_{z,t+1} i_{t+1}^R / i_t^R\right) g_{z,t+1}\left(\frac{i_{t+1}^R}{i_t^R}\right)^2\right] \tag{C.1.2}$$

$$Q_t = \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t} g_{z,t+1}^{-1}\Big((1-\delta)Q_{t+1} + (1-\tau_{t+1}^k) r_{K,t+1} u_{t+1} + \left(\tau_{t+1}^k \delta - \left(1-\tau_t^k\right)\Gamma_u(u_{t+1})\right) p_{I,t+1}\Big)\right] \tag{C.1.3}$$

$$r_{K,t} = \Gamma_u'(u_t) p_{I,t+1} \tag{C.1.4}$$

$$\beta \varepsilon_t^{RP} R_t E_t\left[\frac{\lambda_{t+1}}{\lambda_t} g_{z,t+1}^{-1} \pi_{C,t+1}^{-1}\right] = 1 \tag{C.1.5}$$

$$\beta\left(1 - \Gamma_{B^*}\left(s_{B^*,t+1}; \varepsilon_t^{RP^*}\right)\right) R_t^* E_t\left[\frac{\lambda_{t+1}}{\lambda_t} g_{z,t+1}^{-1} \pi_{C,t+1}^{-1} \frac{s_{t+1}}{s_t} \frac{\pi_{Y,t+1}}{\pi_{Y,t+1}^*}\right] = 1 \tag{C.1.6}$$

where $p_{I,t} = P_{I,t}/P_{C,t}$ is the relative price of the investment good, $r_{K,t} = R_{K,t}/P_{C,t}$ is the real rental rate of capital, $s_t = S_t P_{Y,t}^* / P_{Y,t}$ is the real exchange rate defined in terms of domestic and foreign output deflators. $\pi_{Y,t} = P_{Y,t}/P_{Y,t-1}$ and $\pi_{Y,t}^* = P_{Y^*,t}/P_{Y^*,t-1}$ denotes, respectively, domestic and foreign gross inflation rates.

The stationary capital accumulation equation (4.3.6) is given by:

$$k_{t+1}^R = (1-\delta) g_{z,t}^{-1} k_t^R + \varepsilon_t^i \left(1 - \Gamma_I\left(g_{z,t} i_t^R / i_{t-1}^R\right)\right) i_t^R \tag{C.1.7}$$

where $k_t^R = K_t^R / z_{t-1}$.

The transformation of the adjustment cost function (4.3.7) yields the following expression, using the fact that the foreign risk premium (4.3.4) and capital utilisation cost functions (4.3.5) are already in stationary form:

$$\Gamma_I\left(g_{z,t} i_t^R / i_{t-1}^R\right) = \frac{\gamma_I}{2}\left(g_{z,t} \frac{i_t^R}{i_{t-1}^R} - g_z\right)^2 \tag{C.1.8}$$

The log-linearised versions of the transformed first order conditions stated above are given by:

$$\hat{\lambda}_t = -\frac{1}{1-\kappa g_z^{-1}}\hat{\tilde{c}}_t^R + \frac{\kappa g_z^{-1}}{1-\kappa g_z^{-1}}\hat{\tilde{c}}_{t-1}^R - \frac{\kappa g_z^{-1}}{1-\kappa g_z^{-1}}\hat{g}_{z,t} - \frac{1}{1+\tau^c}\hat{\tau}_t^c + \frac{1}{\nu_G}\left(\hat{\tilde{c}}_t^R - \hat{c}_t^R\right) + \hat{\varepsilon}_t^c \quad \text{(C.1.9)}$$

$$\hat{p}_{I,t} = \hat{Q}_t + \hat{\varepsilon}_t^I + \gamma_I g_z^2 \left(\beta\left(E_t\left[\hat{i}_{t+1}^R\right] - \hat{i}_t^R\right) - \left(\hat{i}_t^R - \hat{i}_{t-1}^R\right) + \beta E_t\left[\hat{g}_{z,t+1}\right] - \hat{g}_{z,t}\right) \quad \text{(C.1.10)}$$

$$\begin{aligned}\hat{Q}_t = {} & \frac{\beta(1-\delta)}{g_z}E_t\left[\hat{Q}_{t+1}\right] + E_t\left[\hat{\lambda}_{t+1}\right] - \hat{\lambda}_t - E_t\left[\hat{g}_{z,t+1}\right] \\ & - \frac{\beta(1-\tau^K)r_K}{g_z}E_t\left[\frac{1}{1-\tau^K}\hat{\tau}_{t+1}^K - \hat{r}_{K,t+1}\right] + \frac{\beta\delta p_I}{g_z}E_t\left[\tau^K\hat{p}_{I,t+1} + \hat{\tau}_{t+1}^K\right] \quad \text{(C.1.11)}\end{aligned}$$

$$\hat{r}_{K,t} = \frac{\gamma_{u,2}}{\gamma_{u,1}}\hat{u}_t + \hat{p}_{I,t} \quad \text{(C.1.12)}$$

$$E_t\left[\hat{\lambda}_{t+1}\right] - \hat{\lambda}_t - E_t\left[\hat{g}_{z,t+1}\right] + \hat{r}_t - E_t\left[\hat{\pi}_{C,t+1}\right] + \hat{\varepsilon}_t^{RP} = 0 \quad \text{(C.1.13)}$$

$$\begin{aligned}& E_t\left[\hat{\lambda}_{t+1}\right] - \hat{\lambda}_t - E_t\left[\hat{g}_{z,t+1}\right] + \hat{r}_t^* - E_t\left[\hat{\pi}_{C,t+1}\right] \\ & \quad + E_t\left[\hat{s}_{t+1}\right] - \hat{s}_t + E_t\left[\hat{\pi}_{Y,t+1} - \hat{\pi}_{Y,t+1}^*\right] - \gamma_{B^*}\hat{s}_{B^*,t+1} - \hat{\varepsilon}_t^{RP^*} = 0 \quad \text{(C.1.14)}\end{aligned}$$

After substituting for the transformed adjustment cost function in (C.1.7), the log-linearised capital accumulation equation is given by:

$$\hat{k}_{t+1} = (1-\delta)g_z^{-1}\hat{k}_t - (1-\delta)g_z^{-1}\hat{g}_{z,t} + (1-(1-\delta)g_z^{-1})\hat{\varepsilon}_t^i + (1-(1-\delta)g_z^{-1})\hat{i}_t \quad \text{(C.1.15)}$$

Combining he log-linearised first-order conditions for the domestic and foreign bond holdings, (C.1.13) and (C.1.14), yields the following risk-adjusted uncovered interest parity (UIP) condition:

$$\hat{r}_t - \hat{r}_t^* + \hat{\varepsilon}_t^{RP} = E_t\left[\hat{s}_{t+1}\right] - \hat{s}_t + E_t\left[\hat{\pi}_{Y,t+1} - \hat{\pi}_{Yt+1}^*\right] - \gamma_{B^*}\hat{s}_{B^*,t+1} - \hat{\varepsilon}_t^{RP^*} \quad \text{(C.1.16)}$$

Wage setting and aggregate wage dynamics

Aggregate wage dynamics is determined by a wage Phillips curve. Let $\hat{\bar{\pi}}_{C,t} = \log\left(\bar{\pi}_{C,t}/\bar{\pi}_C\right)$ denote the log-deviation of the monetary authority's inflation objective from its long-run value, and recall that $w_t = W_t/(z_t P_{C,t})$. Using these definitions and combining the log-linearised first-order condition characterising the optimal wage-setting decision (4.3.16) and the log-linearised aggregate wage index (4.3.18) yields the following log-linear expression for the wage Phillips curve:

$$\begin{aligned}\hat{w}_t = \frac{\beta}{1+\beta}E_t\left[\hat{w}_{t+1}\right] + \frac{1}{1+\beta}\hat{w}_{t-1} + \frac{\beta}{1+\beta}E_t\left[\hat{\pi}_{C,t+1}\right] \\ - \frac{1+\beta\chi_W}{1+\beta}\hat{\pi}_{C,t} + \frac{\chi_W}{1+\beta}\hat{\pi}_{C,t-1} - \frac{\beta(1-\chi_W)}{1+\beta}E_t\left[\hat{\bar{\pi}}_{C,t+1}\right] \\ + \frac{1-\chi_W}{1+\beta}\hat{\bar{\pi}}_{C,t} - \frac{(1-\beta\theta_W)(1-\theta_W)}{(1+\beta)\theta_W\Psi(\phi^W,\sigma_L)}\left(\hat{w}_t^{\tau} - \widehat{mrs}_t - \hat{\phi}_t^W\right)\end{aligned} \quad \text{(C.1.17)}$$

where the terms

$$\hat{w}_t^{\tau} = -\frac{\hat{\tau}_t^w}{1-\tau^w} + \hat{w}_t$$

$$\widehat{mrs}_t = \hat{\varepsilon}_t^n + \sigma_L\hat{N}_t - \hat{\lambda}_t$$

denote the tax and productivity-adjusted real wage, and the household's marginal rate of substitution between consumption and leisure, respectively.

Finally,

$$\Psi(\phi^W,\sigma_L) = 1 + \frac{\phi^W}{\phi^W-1}\sigma_L$$

Non-Ricardian households

With respect to household budget constraints and non-Ricardian household consumption, it is enough to log-linearise the non-Ricardian budget constraint (4.3.14):

$$(1+\tau^c)\,\hat{c}^{NR}\left(\frac{1}{1+\tau^c}\hat{\tau}_t^c + \hat{c}_t^{NR}\right) - (1-\tau^w)\,wN\left(\frac{1}{1-\tau^w}\hat{\tau}_t^w + \hat{w}_t + \hat{N}_t\right) - \hat{tr}_t^{NR} = 0 \quad \text{(C.1.18)}$$

C.1.3 Firms

Domestic intermediate-good firms

This section derives the log-linear equations characterising the behaviour of intermediate-good producers. For ease of exposition, combined with the fact that all firms make identical decisions in equilibrium, the subscript f is dropped.

Technology, inputs and marginal cost

The stationary production function (4.3.19) is given by:

$$y_t = \varepsilon_t\left(g_{z,t}^{-1}\tilde{k}_t\right)^{\alpha}N_t^{1-\alpha} - \psi \quad \text{(C.1.19)}$$

Similarly, the transformation of (4.3.28) yields the following stationary version of the firm's first order condition:

$$\frac{r_{K,t}}{w_t} = \frac{\alpha}{1-\alpha}\frac{g_{z,t}N_t}{k_t^s}\left[1+\left(\frac{1-\alpha_K}{\alpha_K}\right)^{\frac{1}{\nu_K}}\left(\frac{k_{G,t}}{k_t^s}\right)^{\frac{\nu_K-1}{\nu_K}}\right]^{-1} \tag{C.1.20}$$

while the transformation of the marginal cost schedule (4.3.29) gives:

$$mc_t = \frac{1}{\varepsilon_t\alpha^\alpha(1-\alpha)^{1-\alpha}}\left(r_{K,t}\right)^\alpha\left(w_t\right)^{1-\alpha}\left(\frac{k_t^s}{\tilde{k}_t}\right)^\alpha\left[1+\left(\frac{1-\alpha_K}{\alpha_K}\right)^{\frac{1}{\nu_K}}\left(\frac{k_{G,t}}{k_t^s}\right)^{\frac{\nu_K-1}{\nu_K}}\right]^\alpha \tag{C.1.21}$$

Log-linearised these equations results in the following expressions for the production technology, the first-order condition and the marginal cost schedule:

$$\hat{y}_t = \left(1+\psi y^{-1}\right)\left(\hat{\varepsilon}_t+\alpha\left(\hat{\tilde{k}}_t-\hat{g}_{z,t}\right)+(1-\alpha)\,N_t\right) \tag{C.1.22}$$

$$\hat{r}_{K,t} = \hat{g}_{z,t}+\hat{N}_t+\hat{w}_t-\hat{k}_t^s-\frac{\nu_K-1}{\nu_K}\left[\frac{\left(\frac{1-\alpha_K}{\alpha_K}\right)^{\frac{1}{\nu_K}}\left(\frac{k_G}{k^s}\right)^{\frac{\nu_K-1}{\nu_K}}}{1+\left(\frac{1-\alpha_K}{\alpha_K}\right)^{\frac{1}{\nu_K}}\left(\frac{k_G}{k^s}\right)^{\frac{\nu_K-1}{\nu_K}}}\right]\left(\hat{k}_{G,t}-\hat{k}_t^s\right) \tag{C.1.23}$$

$$\hat{mc}_t = -\hat{\varepsilon}_t+\alpha\hat{r}_{K,t}+(1-\alpha)\hat{w}_t+\alpha\left(\hat{k}_t^s-\hat{\tilde{k}}_t\right)+\alpha\frac{\nu_K-1}{\nu_K}\left[\frac{\left(\frac{1-\alpha_K}{\alpha_K}\right)^{\frac{1}{\nu_K}}\left(\frac{k_G}{k^s}\right)^{\frac{\nu_K-1}{\nu_K}}}{1+\left(\frac{1-\alpha_K}{\alpha_K}\right)^{\frac{1}{\nu_K}}\left(\frac{k_G}{k^s}\right)^{\frac{\nu_K-1}{\nu_K}}}\right]\left(\hat{k}_{G,t}-\hat{k}_t^s\right) \tag{C.1.24}$$

Public capital accumulation is analogous to that for private capital and is given by

$$\hat{k}_{G,t+1} = (1-\delta)g_z^{-1}\hat{k}_{G,t}-(1-\delta)g_z^{-1}\hat{g}_{z,t}+(1-(1-\delta)g_z^{-1})\hat{\varepsilon}_t^i+(1-(1-\delta)g_z^{-1})\hat{i}_{G,t} \tag{C.1.25}$$

Finally, the log-linear version of the expression for aggregate capital used in production is

$$\hat{\tilde{k}}_t = \alpha_K^{\frac{1}{\nu_K}}\left(\frac{k^s}{\tilde{k}}\right)^{\frac{\nu_K-1}{\nu_K}}\hat{k}_t^s+(1-\alpha_K)^{\frac{1}{\nu_K}}\left(\frac{k_G}{\tilde{k}}\right)^{\frac{\nu_K-1}{\nu_K}}\hat{k}_{G,t} \tag{C.1.26}$$

Price setting and price dynamics

The domestic and export Phillips curves are presented in the main body of the text in (4.3.42) and (4.3.43), and are repeated here for convenience:

$$\begin{aligned}\left(\hat{\pi}_{H,t}-\hat{\bar{\pi}}_{C,t}\right) = {} & \frac{\beta}{1+\beta\chi_H}E_t\left[\hat{\pi}_{H,t+1}-\hat{\bar{\pi}}_{C,t+1}\right]+\frac{\chi_H}{1+\beta\chi_H}\left(\hat{\pi}_{H,t-1}-\hat{\bar{\pi}}_{C,t}\right)\\ & +\frac{\beta\chi_H}{1+\beta\chi_H}E_t\left[\hat{\bar{\pi}}_{C,t+1}-\hat{\bar{\pi}}_{C,t}\right]+\frac{(1-\beta\theta_H)\,(1-\theta_H)}{\theta_H\,(1+\beta\chi_H)}\left(\widehat{mc}_t^H+\hat{\phi}_t^H\right)\end{aligned} \tag{C.1.27}$$

$$\begin{aligned}\left(\hat{\pi}_{X,t}-\hat{\bar{\pi}}_{C,t}\right) = {} & \frac{\beta}{1+\beta\chi_X}E_t\left[\hat{\pi}_{X,t+1}-\hat{\bar{\pi}}_{C,t+1}\right]+\frac{\chi_X}{1+\beta\chi_X}\left(\hat{\pi}_{X,t-1}-\hat{\bar{\pi}}_{C,t}\right)\\ & +\frac{\beta\chi_X}{1+\beta\chi_X}E_t\left[\hat{\bar{\pi}}_{C,t+1}-\hat{\bar{\pi}}_{C,t}\right]+\frac{(1-\beta\theta_X)\,(1-\theta_X)}{\theta_X\,(1+\beta\chi_X)}\left(\widehat{mc}_t^X+\hat{\phi}_t^X\right)\end{aligned} \tag{C.1.28}$$

Foreign intermediate-good firm

As with the domestic intermediate-good firms, the optimal price-setting decision of the foreign intermediate-good firm and the dynamics of the aggregate import price index can be summarised by a Phillips-curve relationship given by (4.3.49) and repeated here for convenience:

$$\begin{aligned}\left(\hat{\pi}_{IM,t}-\hat{\bar{\pi}}_{C,t}\right) &= \frac{\beta^*}{1+\beta^*\chi^*}E_t\left[\hat{\pi}_{IM,t+1}-\hat{\bar{\pi}}_{C,t+1}\right]+\frac{\chi^*}{1+\beta^*\chi^*}\left(\hat{\pi}_{IM,t-1}-\hat{\bar{\pi}}_{C,t}\right)\\ &+\frac{\beta^*\chi^*}{1+\beta^*\chi^*}E_t\left[\hat{\bar{\pi}}_{C,t+1}-\hat{\bar{\pi}}_{C,t}\right]+\frac{(1-\beta^*\theta^*)(1-\theta^*)}{\theta^*(1+\beta^*\chi^*)}\left(\widehat{mc}_t^*+\hat{\phi}_t^*\right)\end{aligned} \quad \text{(C.1.29)}$$

Domestic final-good firms

Applying the stationarity inducing transformations to the expressions for the consumption good technology (4.3.50) and the relevant demand schedules (4.3.57) and (4.3.58) yields:

$$q_t^C=\left(\nu_C^{\frac{1}{\mu_C}}\left(h_t^C\right)^{1-\frac{1}{\mu_C}}+(1-\nu_C)^{\frac{1}{\mu_C}}\left(im_t^C\right)^{1-\frac{1}{\mu_C}}\right)^{\frac{\mu_C}{\mu_C-1}} \quad \text{(C.1.30)}$$

and

$$h_t^C=\nu_C\left(\frac{p_{H,t}}{p_{C,t}}\right)^{-\mu_C}q_t^C \quad \text{(C.1.31)}$$

$$im_t^C=(1-\nu_C)\left(\frac{p_{IM,t}}{p_{C,t}}\right)^{-\mu_C}q_t^C \quad \text{(C.1.32)}$$

Similarly, the transformed price index for the final consumption good (4.3.59) is:

$$p_{C,t}=\left(\nu_C\left(p_{H,t}\right)^{1-\mu_C}+(1-\nu_C)\left(p_{IM,t}\right)^{1-\mu_C}\right)^{\frac{1}{1-\mu_C}} \quad \text{(C.1.33)}$$

The log-linearised equations for the consumption good technology and demand schedules are given by:

$$\hat{q}_t^C=\nu_C^{\frac{1}{\mu_C}}\left(\frac{h^C}{q^C}\right)^{1-\frac{1}{\mu_C}}\hat{h}_t^C+(1-\nu_C)^{\frac{1}{\mu_C}}\left(\frac{im^C}{q^C}\right)^{1-\frac{1}{\mu_C}}\widehat{im}_t^C \quad \text{(C.1.34)}$$

and

$$\hat{h}_t^C=\hat{q}_t^C-\mu_C\left(\hat{p}_{H,t}-\hat{p}_{C,t}\right) \quad \text{(C.1.35)}$$

$$\widehat{im}_t^C=\hat{q}_t^C-\mu_C\left(\hat{p}_{IM,t}-\hat{p}_{C,t}\right) \quad \text{(C.1.36)}$$

The log-linear version of the aggregate consumption price index is:

$$\hat{p}_{C,t}=\nu_C\left(\frac{p_H}{p_C}\right)^{1-\mu_C}\hat{p}_{H,t}+(1-\nu_C)\left(\frac{p_{IM}}{p_C}\right)^{1-\mu_C}\left(\hat{p}_{IM,t}\right) \quad \text{(C.1.37)}$$

with $p_C = 1$ and $\hat{p}_{C,t} = 0$ by definition.

With an obvious change in notation, similar expressions can be obtained for the investment good, Q_t^I, the demand bundles H_t^I and IM_t^I, and the price index $P_{I,t}$. In contrast, public consumption and investment goods comprise only intermediate goods, with trivial expressions $\hat{q}_t^G = \hat{h}_t^G$ and $\hat{q}_t^{I_G} = \hat{h}_t^{I_G}$, and $\hat{p}_{G,t} = \hat{p}_{H,t}$ and $\hat{p}_{I_G,t} = \hat{p}_{H,t}$.

Finally, aggregating across the four final-good firms gives the following log-linear expressions for the relevant demand bundles:

$$\hat{h}_t = \frac{h^C}{h}\hat{h}_t^C + \frac{h^I}{h}\hat{h}_t^I + \frac{h^G}{h}\hat{h}_t^G + \frac{h^{I_G}}{h}\hat{h}_t^{I_G} \tag{C.1.38}$$

$$\widehat{im}_t = \frac{im^C}{im}\widehat{im}_t^C + \frac{im^I}{im}\widehat{im}_t^I \tag{C.1.39}$$

Foreign retail firm

As noted in Christoffel et al. (2008), for the foreign retail firm it is sufficient to derive a log-linear expression for the export bundle X_t given by (4.3.68):

$$x_t = \nu^* \left(\frac{p_{X,t}}{p_{Y,t}s_t}\right)^{-\mu^*} y_t^* \tilde{z}_t \tag{C.1.40}$$

where foreign demand Y_t^* is scaled by the foreign productivity level z_t^* and $\tilde{z}_t = z_t^*/z_t$ denotes the productivity differential between the domestic and foreign economies. $\tilde{z}_t$ is a stationary process capturing the degree of asymmetry in productivity between the two countries. Given that it is assumed that z_t and z_t^* share the same stochastic trend, combined with the assumption that $z_0 = z_0^*$, the implied productivity levels in the domestic and foreign economies are equal in the non-stochastic steady state, i.e. $\tilde{z} = 1$.

Therefore, the log-linear expression for the export bundle is given by:

$$\hat{x}_t = \hat{y}_t^* - \mu^* \left(\hat{p}_{X,t} - \hat{p}_{Y,t} - \hat{s}_t\right) + \hat{\tilde{z}}_t \tag{C.1.41}$$

C.1.4 Fiscal and monetary authorities

Expressing the fiscal authority's budget constraint (4.3.71) as a share of nominal output results in the following expression for the budget constraint:

$$s_{G,t} = \tau_t^c \frac{P_{C,t}C_t}{P_{Y,t}Y_t} + \tau_t^w \frac{W_t N_t}{P_{Y,t}Y_t} - \frac{P_{I_G,t}I_{G,t}}{P_{Y,t}Y_t} + \tau_t^k u_t \frac{R_{K,t}K_t}{P_{Y,t}Y_t} - \tau_t^k \left(\Gamma_u(u_t) + \delta\right) \frac{P_{I,t}K_t}{P_{Y,t}Y_t} + \frac{B_{t+1}}{R_t P_{Y,t}Y_t} - \frac{B_t}{P_{Y,t}Y_t} - s_{TR,t} \tag{C.1.42}$$

where $s_{G,t} = P_{G,t}G_t/P_{Y,t}Y_t$ and $s_{TR,t} = TR_t/P_{Y,t}Y_t$ represents that shares of the public consumption good and transfer in nominal output.

Applying the above-mentioned stationarity inducing transformation, the budget constraint (C.1.42) can be expressed:

$$s_{G,t} = \tau_t^c \frac{p_{C,t}c_t}{p_{Y,t}y_t} + \tau_t^w \frac{w_t N_t}{p_{Y,t}y_t} - \frac{p_{I_G,t}i_{G,t}}{p_{y,t}y_t} + \tau_t^k u_t \frac{r_{K,t}k_t g_{z,t}^{-1}}{p_{Y,t}y_t} - \tau_t^k \left(\Gamma_u(u_t) + \delta\right) \frac{p_{I,t}k_t g_{z,t}^{-1}}{p_{Y,t}y_t}$$
$$+ \frac{b_{t+1}R_t^{-1}}{p_{Y,t}y_t} - \frac{b_t \pi_{C,t}^{-1} g_{z,t}^{-1}}{p_{Y,t}y_t} - s_{TR,t} \quad \text{(C.1.43)}$$

where $b_{t+1} = B_{t+1}/z_t P_{C,t}$.

The following log-linearised expression is obtained (recalling that $u = 1$, $\Gamma_u(1) = 0$ and $\Gamma_u^{'}(1) = r_K p_I^{-1}$):

$$\begin{aligned}\hat{s}_{G,t} =& \frac{p_C c}{p_Y y}\left(\hat{\tau}_t^c + \tau^c\left(\hat{p}_{C,t} + \hat{c}_t - \hat{p}_{Y,t} - \hat{y}_t\right)\right) \\ &+ \frac{wN}{p_Y y}\left(\hat{\tau}_t^w + \tau^w\left(\hat{w}_t + \hat{N}_t - \hat{p}_{Y,t} - \hat{y}_t\right)\right) \\ &- \frac{p_{I_G} i_G}{p_Y y}\left(\hat{p}_{I_G,t} + \hat{i}_{G,t} - \hat{p}_{Y,t} - \hat{y}_t\right) \\ &+ \frac{r_K k g_z^{-1}}{p_Y y}\left(\hat{\tau}_t^k + \tau^k\left(\hat{u}_t + \hat{r}_{K,t} + \hat{k}_t - \hat{g}_{z,t} - \hat{p}_{Y,t} - \hat{y}_t\right)\right) \\ &- \frac{p_I k g_z^{-1}}{p_Y y}\left(\gamma_{u,1}\hat{u}_t + \tau^k\delta\left(\hat{\tau}_t^k + \hat{p}_{I,t} + \hat{k}_t - \hat{g}_{z,t} - \hat{p}_{Y,t} - \hat{y}_t\right)\right) \\ &+ \frac{bR^{-1}}{p_Y y}\left(\hat{b}_{t+1} - \hat{r}_t - \hat{p}_{Y,t} - \hat{y}_t\right) - \frac{b\pi_C^{-1} g_z^{-1}}{p_Y y}\left(\hat{b}_t - \hat{\pi}_{C,t} - \hat{g}_{z,t} - \hat{p}_{Y,t} - \hat{y}_t\right) \\ &- \hat{s}_{TR,t}\end{aligned} \quad \text{(C.1.44)}$$

where

$$\hat{s}_{G,t} = s_G\left(\hat{p}_{G,t} + \hat{g}_t - \hat{p}_{Y,t} - \hat{y}_t\right) \quad \text{(C.1.45)}$$

Finally, the behaviour of the monetary authority is fully described by the simple log-linear Taylor rule presented in the main text (equation (4.3.69)).

C.1.5 Market clearing and aggregate resource constraint

Transformation and log-linearisation of the market clearing conditions (4.3.82), (4.3.87), (4.3.88) and (4.3.90) yields:

$$\hat{k}_t^s = \hat{u}_t + \hat{k}_t \quad \text{(C.1.46)}$$
$$\hat{q}_t^C = \hat{c}_t \quad \text{(C.1.47)}$$
$$\hat{q}_t^I = \hat{i}_t + r_K p_I^{-1} g_z^{-1} \frac{k}{q^I}\hat{u}_t \quad \text{(C.1.48)}$$
$$\hat{q}_t^{I_G} = \hat{i}_{G,t} \quad \text{(C.1.49)}$$
$$\hat{q}_t^G = \hat{g}_t \quad \text{(C.1.50)}$$

Similarly, applying the appropriate stationarity inducing transformations and log-linearisation of (4.3.84) and (4.3.91) yields the following lo-linear expressions for the real and nominal versions of the aggregate resource constraint:

$$\hat{y}_t = \frac{h}{y}\hat{h}_t + \frac{x}{y}\hat{x}_t \tag{C.1.51}$$

and

$$\begin{aligned}\hat{p}_{Y,t} + \hat{y}_t =& \frac{p_C c}{p_Y y}\left(\hat{p}_{C,t} + \hat{c}_t\right) + \frac{p_I i}{p_Y y}\left(\hat{p}_{I,t} + \hat{i}_t\right) + \frac{p_I k g_z^{-1}}{p_Y y}\gamma_{u,1}\hat{u}_t + \frac{p_{I_G} i_G}{p_Y y}\left(\hat{p}_{I_G,t} + \hat{i}_{G,t}\right) \\ &+ \frac{p_G g}{p_Y y}\left(\hat{p}_{G,t} + \hat{g}_t\right) + \frac{p_X x}{p_Y y}\left(\hat{p}_{X,t} + \hat{x}_t\right) \\ &- \frac{p_{IM} im^C}{p_Y y}\left(\hat{p}_{IM,t} + \hat{im}_t^C\right) - \frac{p_{IM} im^I}{p_Y y}\left(\hat{p}_{IM,t} + \hat{im}_t^I\right)\end{aligned} \tag{C.1.52}$$

recalling that $p_C = 1$ and $\hat{p}_{C,t} = 0$.

C.1.6 Net foreign assets and the trade balance

Substituting the definition of the trade balance (4.3.96) into the expression for the net foreign asset position (4.3.95) and scaling by z_t^* and $P_{Y,t}^*$, results in:

$$\frac{b_{t+1}^*}{R_t^*} = b_t^* \tilde{z}_{t-1}\tilde{z}_t^{-1} g_{z,t}^{-1}\left(\pi_{Y,t}^*\right)^{-1} + \frac{p_{x,t}}{s_t p_{Y,t}} x_t \tilde{z}_t^{-1} - \frac{p_{IM,t}}{s_t p_{Y,t}} im_t \tilde{z}_t^{-1} \tag{C.1.53}$$

where $b_{t+1}^* = B_{t+1}^*/\left(z_t^* P_{Y,t}^*\right)$, $\pi_{Y,t}^* = P_{Y,t}^*/P_{Y,t-1}^*$ and $s_t = S_t P_{Y,t}^*/P_{Y,t}$.

Log-linearising this expression gives:

$$\frac{\hat{b}_{t+1}^*}{R^*} = g_z^{-1}\left(\pi_Y^*\right)^{-1}\hat{b}_t^* + \frac{p_X x}{s p_Y}\left(\hat{p}_{X,t} + \hat{x}_t - \hat{s}_t - \hat{p}_{Y,t} - \hat{\tilde{z}}_t\right) - \frac{p_{IM} im}{s p_Y}\left(\hat{p}_{IM,t} + \widehat{im}_t - \hat{s}_t - \hat{p}_{Y,t} - \hat{\tilde{z}}_t\right) \tag{C.1.54}$$

The log-linear version of the law of motion for the net foreign asset position, expressed in domestic currency and as a share of domestic output, $s_{B^*;t+1} = S_t B_{t+1}^*/(P_{Y,t}Y_t) = s_t b_{t+1}^* \tilde{z}_t/y_t$, is given by:

$$\hat{s}_{B^*;t+1} = s\tilde{z}y^{-1}\hat{b}_{t+1}^* \tag{C.1.55}$$

with $s = 1$ and $\tilde{z} = 1$.

C.1.7 Relative prices

Relative prices are assumed to be stationary and related to the various inflation rates through a set of identities. Using the price of the domestic consumption good as the numeraire, the price indices for the domestic intermediate good sold domestically or abroad evolve, after log-linearisation, according to

$$\hat{p}_{H,t} = \hat{p}_{H,t-1} + \hat{\pi}_{H,t} - \hat{\pi}_{C,t} \tag{C.1.56}$$

$$\hat{p}_{X,t} = \hat{p}_{X,t-1} + \hat{\pi}_{X,t} - \hat{\pi}_{C,t} \tag{C.1.57}$$

Similarly, the relative price of aggregate domestic output is given by

$$\hat{p}_{Y,t} = \hat{p}_{Y,t-1} + \hat{\pi}_{Y,t} - \hat{\pi}_{C,t} \tag{C.1.58}$$

The relative price of the consumption and investment good evolve according to

$$\hat{p}_{C,t} = 0 \tag{C.1.59}$$

$$\hat{p}_{I,t} = \hat{p}_{I,t-1} + \hat{\pi}_{I,t} - \hat{\pi}_{C,t} \tag{C.1.60}$$

Finally, for the price of the imported intermediate good we obtain

$$\hat{p}_{IM,t} = \hat{p}_{IM,t-1} + \hat{\pi}_{IM,t} - \hat{\pi}_{C,t} \tag{C.1.61}$$

C.1.8 Normalisations

Following Christoffel et al. (2008) and Coenen et al. (2013), some of the structural shocks in the log-linearised model are normalised. The normalisations make it easier to choose reasonable priors for the standard deviations of the innovations to the structural shocks. In the case of the domestic Phillips curve (C.1.27), the normalisation entails defining a new variable $\hat{\phi}_t^{H,\dagger} = B\hat{\phi}_t^H$, where $B = (1-\beta\theta_H)(1-\theta_H)/(\theta_H(1+\beta\chi_H))$, and estimating the standard deviation of the shock to $\hat{\phi}_t^{H,\dagger}$ instead of $\hat{\phi}_t^H$. This normalisation implies that the price markup shock enters the Phillips curve with a unit coefficient. The same is done for the markup shocks $\hat{\phi}_t^X$, $\hat{\phi}_t^*$ and $\hat{\phi}_t^W$ in the export and import price Phillips curves (C.1.28) and (C.1.29) and in the wage Phillips curve (C.1.17).

C.2 Steady state

C.2.1 The household's allocation

Using the stationarity inducing transformations as outlined above, the steady-state version of the first-order condition characterising the Ricardian household's optimal purchases of the consumption good (equation (4.3.8 in the main text) is given by:

$$\lambda = \alpha_G^{\frac{1}{\nu_G}} \frac{1}{(1-\kappa g_z)(1+\tau^c)\tilde{c}^R} \left(\frac{\tilde{c}^R}{c^R}\right)^{\frac{1}{\nu_G}} \tag{C.2.1}$$

Similarly, the first-order condition for the optimal purchase of the investment good (4.3.9) reduces to:

$$p_I = Q \tag{C.2.2}$$

The conditions characterising the optimal holdings of capital (4.3.10) results in the following expression for Q:

$$Q = \frac{1 - \tau^k}{g_z \beta^{-1} + \delta - 1 - \tau^k \delta} r_K \tag{C.2.3}$$

Evaluating the first-order condition for the capital stock at steady state and making use of the condition for the optimal utilisation of capital (4.3.11),

$$r_K = \gamma_{u,1} p_I \tag{C.2.4}$$

gives the first derivative of the capital adjustment cost function:

$$\gamma_{u,1} = \frac{r_K}{p_I} = \frac{1}{1 - \tau^k} \left(g_z \beta^{-1} + \delta - 1 - \tau^k \delta \right) \tag{C.2.5}$$

Finally, the steady-state version of the capital accumulation equation is given by:

$$i = \left(1 - \frac{1 - \delta}{g_z} \right) k \tag{C.2.6}$$

C.2.2 Labour-market equilibrium

On the labour supply side, the first-order condition characterising the household's optimal wage-setting decision (4.3.16) yields the following expression:

$$(1 - \tau^w)\, w = \phi^W \frac{N^{\sigma_L}}{\lambda} \tag{C.2.7}$$

Using the first-order condition (C.2.1), this can be re-written as:

$$(1 - \tau^w)\, w = \alpha_G^{-\frac{1}{\nu_G}} \phi^W N^{\sigma_L} (1 + \tau^c) \left(1 - \kappa g_z^{-1} \right) \tilde{c}^R \left(\frac{\tilde{c}^R}{c^R} \right)^{-\frac{1}{\nu_G}} \tag{C.2.8}$$

Or, alternative;y

$$w = \alpha_G^{-\frac{1}{\nu_G}} \phi^W N^{\sigma_L} \frac{1 + \tau^c}{1 - \tau^w} \left(1 - \kappa g_z^{-1} \right) c^R \left(\frac{\tilde{c}^R}{c^R} \right)^{\frac{\nu_G - 1}{\nu_G}} \tag{C.2.9}$$

Regarding labour demand, combining the first-order conditions characterising the intermediate-good firm's optimal choice of inputs, (4.3.28), and the fact that in steady state $k^s = k$, gives:

$$\frac{r_K}{w} = \frac{\alpha}{1 - \alpha} \frac{N}{k} g_z \left[1 + \left(\frac{1 - \alpha_K}{\alpha_K} \right)^{\frac{1}{\nu_K}} \left(\frac{k_G}{k} \right)^{\frac{\nu_K - 1}{\nu_K}} \right]^{-1} \tag{C.2.10}$$

or

$$w = \frac{1 - \alpha}{\alpha} k N^{-1} g_z^{-1} \left[1 + \left(\frac{1 - \alpha_K}{\alpha_K} \right)^{\frac{1}{\nu_K}} \left(\frac{k_G}{k} \right)^{\frac{\nu_K - 1}{\nu_K}} \right] r_K \tag{C.2.11}$$

The equilibrium condition for the labour market is obtained by combining (C.2.9) and (C.2.11):

$$\alpha_G^{-\frac{1}{\nu_G}} \phi^W N^{\sigma_L} \frac{1+\tau^c}{1-\tau^w} \left(1-\kappa g_z^{-1}\right) c^R \left(\frac{\tilde{c}^R}{c^R}\right)^{\frac{\nu_G-1}{\nu_G}} = \frac{1-\alpha}{\alpha} k N^{-1} g_z^{-1} \left[1+\left(\frac{1-\alpha_K}{\alpha_K}\right)^{\frac{1}{\nu_K}} \left(\frac{k_G}{k}\right)^{\frac{\nu_K-1}{\nu_K}}\right] r_K \quad \text{(C.2.12)}$$

Re-arranging and using (C.2.5) gives:

$$g_z \alpha_G^{-\frac{1}{\nu_G}} \phi^W N^{\sigma_L+1} \frac{1+\tau^c}{1-\tau^w} \left(1-\kappa g_z^{-1}\right) c^R \left(\frac{\tilde{c}^R}{c^R}\right)^{\frac{\nu_G-1}{\nu_G}} k^{-1} = \frac{1-\alpha}{\alpha} \frac{1}{1-\tau_k} \left(g_z \beta^{-1} + \delta - 1 - \tau^k \delta\right) \left[1+\left(\frac{1-\alpha_K}{\alpha_K}\right)^{\frac{1}{\nu_K}} \left(\frac{k_G}{k}\right)^{\frac{\nu_K-1}{\nu_K}}\right] p_I \quad \text{(C.2.13)}$$

This expression can be re-written as follows:

$$g_z \alpha_G^{-\frac{1}{\nu_G}} \frac{\alpha}{1-\alpha} \frac{1+\tau^c}{1-\tau^w} \left(1-\kappa g_z^{-1}\right) \frac{1}{\gamma_{u,1}} \phi^W N^{\sigma_L+1} c^R \left(\frac{\tilde{c}^R}{c^R}\right)^{\frac{\nu_G-1}{\nu_G}} k^{-1} p_I^{-1} \times \left[1+\left(\frac{1-\alpha_K}{\alpha_K}\right)^{\frac{1}{\nu_K}} \left(\frac{k_G}{k}\right)^{\frac{\nu_K-1}{\nu_K}}\right]^{-1} = 1 \quad \text{(C.2.14)}$$

Defining

$$\Theta = g_z \alpha_G^{-\frac{1}{\nu_G}} \frac{\alpha}{1-\alpha} \frac{1+\tau^c}{1-\tau^w} \left(1-\kappa g_z^{-1}\right) \frac{1}{\gamma_{u,1}} \phi^W \left(\frac{\tilde{c}^R}{c^R}\right)^{\frac{\nu_G-1}{\nu_G}} \left[1+\left(\frac{1-\alpha_K}{\alpha_K}\right)^{\frac{1}{\nu_K}} \left(\frac{k_G}{k}\right)^{\frac{\nu_K-1}{\nu_K}}\right]^{-1} \quad \text{(C.2.15)}$$

results in the final expression for the labour market equilibrium:

$$\Theta N^{\sigma_L} c \left(\frac{k}{N}\right)^{-1} p_I^{-1} = 1 \quad \text{(C.2.16)}$$

C.2.3 Capital-market equilibrium

Combining the first-order condition characterising the intermediate-good firms' optimal demand for capital (4.3.26)

$$\frac{r_K}{mc} = \alpha g_z^{1-\alpha} \tilde{k}^{\alpha} k^{-1} N^{1-\alpha} \left[1+\left(\frac{1-\alpha_K}{\alpha_K}\right)^{\frac{1}{\nu_K}} \left(\frac{k_G}{k}\right)^{\frac{\nu_K-1}{\nu_K}}\right]^{-1} \quad \text{(C.2.17)}$$

and the first-order condition for the optimal price setting decision in domestic markets (4.3.38):

$$p_H = \phi^H mc \tag{C.2.18}$$

results in the following equilibrium expression for the capital market:

$$\alpha = g_z^{-(1-\alpha)} \left[1 + \left(\frac{1-\alpha_K}{\alpha_K} \right)^{\frac{1}{\nu_K}} \left(\frac{k_G}{k} \right)^{\frac{\nu_K - 1}{\nu_K}} \right] \tilde{k}^{-\alpha} k N^{-(1-\alpha)} r_K \phi^H p_H^{-1} \tag{C.2.19}$$

This expression can be re-written using (C.2.5):

$$\alpha = g_z^{-(1-\alpha)} \left[1 + \left(\frac{1-\alpha_K}{\alpha_K} \right)^{\frac{1}{\nu_K}} \left(\frac{k_G}{k} \right)^{\frac{\nu_K - 1}{\nu_K}} \right] \tilde{k}^{-\alpha} k N^{-(1-\alpha)} \gamma_{u,1} \phi^H \frac{p_I}{p_H} \tag{C.2.20}$$

C.2.4 Goods-market equilibrium

The following real aggregate resource constraint holds in steady state with respect to the production of intermediate goods:

$$g_z^{-\alpha} \tilde{k}^{\alpha} N^{1-\alpha} - \psi = h + x \tag{C.2.21}$$

Taking into account the identity $h = h^C + h^I + h^{I_G} + h^G$ and recalling that the demand for intermediate goods used in the production of the consumption good is given by:

$$h^C = \nu_C \left(p_H \right)^{-\mu_C} c \tag{C.2.22}$$

the aggregate resource constraint can be re-written as

$$h_I = g_z^{-\alpha} \tilde{k}^{\alpha} N^{1-\alpha} - \psi - x - \nu_C \left(p_H \right)^{-\mu_C} c - h^{I_G} - h^G \tag{C.2.23}$$

Substituting into the expression for the investment-good technology, (4.3.60),

$$i^{1-\frac{1}{\mu_I}} = \nu_I^{\frac{1}{\mu_I}} \left(h^I \right)^{1-\frac{1}{\mu_I}} + (1-\nu_I) \left(im^I \right)^{1-\frac{1}{\mu_I}} \tag{C.2.24}$$

recalling that the demand for imported intermediate goods used in the production of the final investment good is given by

$$im^I = (1-\nu_I) \left(\frac{p_{IM}}{p_I} \right)^{-\mu_I} i \tag{C.2.25}$$

and using (C.2.6), results in the following equilibrium expression for the aggregate resource constraint

$$\left(\frac{g_z - 1 + \delta}{g_z} k \right)^{1-\frac{1}{\mu_I}} = \nu_I^{\frac{1}{\mu_I}} \left(g_z^{-\alpha} \tilde{k}^{\alpha} N^{1-\alpha} - \psi - x - \nu_C \left(p_H \right)^{-\mu_C} c - h^{I_G} - h^G \right)^{1-\frac{1}{\mu_I}} + (1-\nu_I) \left(\frac{p_{IM}}{p_I} \right)^{1-\mu_I} \left(\frac{g_z - 1 + \delta}{g_z} k \right)^{1-\frac{1}{\mu_I}} \tag{C.2.26}$$

or, equivalently

$$\left(\frac{g_z-1+\delta}{g_z}k\right)^{1-\frac{1}{\mu_I}}\left(1-(1-\nu_I)\left(\frac{p_{IM}}{p_I}\right)^{1-\mu_I}\right)= \nu_I^{\frac{1}{\mu_I}}\left(g_z^{-\alpha}\tilde{k}^{\alpha}N^{1-\alpha}-\psi-x-\nu_C\left(p_H\right)^{-\mu_C}c-h^{I_G}-h^{G}\right)^{1-\frac{1}{\mu_I}} \quad \text{(C.2.27)}$$

C.2.5 Equilibrium relative prices

Using the price of the consumption good as the numeraire, equilibrium expressions for the relative price of the intermediate good sold at home and the investment good are given by

$$1=\nu_C\left(p_H\right)^{1-\mu_C}+\left(1-\nu_C\right)\left(p_{IM}\right)^{1-\mu_C} \quad \text{(C.2.28)}$$

and

$$\left(p_I\right)^{1-\mu_I}=\nu_I\left(p_H\right)^{1-\mu_I}+\left(1-\nu_I\right)\left(p_{IM}\right)^{1-\mu_I} \quad \text{(C.2.29)}$$

Re-arranging (C.2.28):

$$p_H=\left(\frac{1-\left(1-\nu_C\right)\left(p_{IM}\right)^{1-\mu_C}}{\nu_C}\right)^{\frac{1}{1-\mu_C}} \quad \text{(C.2.30)}$$

Similarly, re-arranging (C.2.29) gives

$$\frac{p_H}{p_I}=\left(\frac{1-\left(1-\nu_I\right)\left(\frac{p_{IM}}{p_I}\right)^{1-\mu_I}}{\nu_I}\right)^{\frac{1}{1-\mu_I}} \quad \text{(C.2.31)}$$

Finally, given the fact that the prices of the intermediate goods (sold either domestically or abroad) are set as a markup on the same marginal cost measure and the assumption that the markups are identical in domestic and foreign markets, implies that $P_Y=P_H=P_X$. This implies that the relative prices are identical as well, i.e. $p_Y=p_H=p_X$. Finally, the equality of prices also implies that the nominal resource constraint collapses to the real constraint in steady state.

C.2.6 Computation

Collecting equations (C.2.16),(C.2.20), (C.2.27), (C.2.30) and (C.2.31), the steady-state model can be reduced to a set of four equations in the unknown steady-state values of the capital stock, k, private consumption, c, hours worked, N, and the relative price of the investment good, p_I:

1. Labour market equilibrium:

$$\Theta N^{\sigma_L}c\left(\frac{k}{N}\right)^{-1}p_I^{-1}=1 \quad \text{(C.2.32)}$$

2. Capital market equilibrium:

$$\alpha = g_z^{-(1-\alpha)} \left[1 + \left(\frac{1-\alpha_K}{\alpha_K} \right)^{\frac{1}{\nu_K}} \left(\frac{k_G}{k} \right)^{\frac{\nu_K - 1}{\nu_K}} \right] \tilde{k}^{-\alpha} k N^{-(1-\alpha)} \gamma_{u,1} \phi^H \frac{p_I}{p_H} \tag{C.2.33}$$

3. Goods market equilibrium:

$$\left(\frac{g_z - 1 + \delta}{g_z} k \right)^{1-\frac{1}{\mu_I}} \left(1 - (1-\nu_I) \left(\frac{p_{IM}}{p_I} \right)^{1-\mu_I} \right) = \nu_I^{\frac{1}{\mu_I}} \left(g_z^{-\alpha} \tilde{k}^{\alpha} N^{1-\alpha} - \psi - x - \nu_C (p_H)^{-\mu_C} c - h^{I_G} - h^G \right)^{1-\frac{1}{\mu_I}} \tag{C.2.34}$$

4. Equilibrium relative price:

$$\left(\frac{1 - (1-\nu_C)(p_{IM})^{1-\mu_C}}{\nu_C} \right)^{\frac{1}{1-\mu_C}} p_I^{-1} = \left(\frac{1 - (1-\nu_I) \left(\frac{p_{IM}}{p_I} \right)^{1-\mu_I}}{\nu_I} \right)^{\frac{1}{1-\mu_I}} \tag{C.2.35}$$

Conditioning on the relative price of the imported bundle, p_{IM}, the system is solved for the unknown steady-state values using numerical methods. In order to do so, several key steady-state ratios are calibrated in order to pin down $g = h^G$, i^G, x and ψ. First, the desired level of the government consumption and investment shares, $s_G = (p_G g)/(p_Y y)$ and $s_{I_G} = (p_{I_G} i_G)/(p_Y y)$, and private investment share, $s_I = (p_I i)/(p_Y y)$ are chosen to match their empirical counterparts. Second, the desired import shares $s_{IM^C} = (p_{IM} im^C)/(p_Y y)$ and $s_{IM^I} = (p_{IM} im^I)/(p_Y y)$ are calibrated by adjusting the quasi-share parameters ν_C and ν_I. Imposing balanced trade in steady state implies that $s_X = s_{IM} = s_{IM^C} + s_{IM^I}$. The nominal consumption share $s_C = (p_C c)/(p_Y y)$ can then be determined as a residual, i.e. $s_C = 1 - s_I - s_{I_G} - s_G - (s_X - s_{IM})$. Finally, the fixed cost of production ψ is chosen according to $\psi/y = \phi = \phi^H = \phi^X$ such that firms' profits are zero in steady state.

Given the fact that the price of imported goods is set in a monopolistically competitive fashion in the foreign market, the import price P_{IM} is treated as given. Therefore, without loss of generality, the relative price of imports can be normalised to one, i.e $p_{IM} = 1$. As a result, all other relative prices are equal to one as well, i.e $p_I = p_Y = p_H = p_G = p_{I_G} = p_X = 1$. Similarly, treating the foreign price P_Y^* as given, the steady-state level of real exchange rate can be normalised to one, i.e. $s = 1$.

C.3 Prior and posterior distributions

Table C.1: Parameter priors and posterior estimation results

Parameter description		Prior			Posterior	
		Density[a]	Mean	Std. dev	Mean	90% interval
Share of non-Ricardian households						
ω	Total share	B	0.5	0.1	0.233	[0.218, 0.249]
$\bar{\omega}$	Transfer share	B	0.75	0.1	0.460	[0.328, 0.592]
Adjustment costs						
γ_I	Investment	G	8.0	1.5	9.493	[7.095, 11.802]
Preferences						
κ	Habit formation	B	0.65	0.1	0.891	[0.858, 0.922]
Elasticity of substitution						
ν_K	Capital	G	1.0	0.2	0.921	[0.606, 1.231]
ν_G	Consumption	G	1.0	0.2	1.013	[0.683, 1.319]
Calvo parameters						
θ_H	Domestic prices	B	0.8	0.05	0.861	[0.787, 0.938]
θ_X	Export prices	B	0.8	0.05	0.933	[0.907, 0.961]
θ^*	Import prices	B	0.8	0.05	0.939	[0.905, 0.973]
Indexation						
χ_H	Domestic prices	B	0.75	0.1	0.447	[0.285, 0.608]
χ_X	Export prices	B	0.75	0.1	0.234	[0.139, 0.324]
χ^*	Import prices	B	0.75	0.1	0.360	[0.224, 0.498]
Taylor rule						
ϕ_R	Smoothing	B	0.8	0.05	0.919	[0.901. 0.939]
ϕ_π	Inflation	N	1.7	0.1	1.767	[1.530, 2.004]
ϕ_Y	Output gap	B	0.25	0.05	0.261	[0.187, 0.335]
$\phi_{\Delta\pi}$	Inflation (change)	B	0.3	0.1	0.168	[0.120, 0.219]
$\phi_{\Delta Y}$	Output gap (change)	B	0.125	0.05	0.165	[0.111, 0.220]
Fiscal policy rules: smoothing coefficients						
ϕ_G	Gvt. consumption	B	0.8	0.15	0.833	[0.708, 0.956]
ϕ_{I_G}	Gvt. investment	B	0.8	0.15	0.582	[0.356, 0.837]
ϕ_{TR}	Transfers	B	0.8	0.15	0.187	[0.059, 0.313]
ϕ_W	Labour taxes	B	0.5	0.2	0.147	[0.048, 0.242]
ϕ_K	Capital taxes	B	0.5	0.2	0.176	[0.058, 0.292]
ϕ_C	Consumption taxes	B	0.5	0.2	0.144	[0.046, 0.237]
Fiscal policy rules: output feedback coefficients						
$\theta_{G,Y}$	Gvt. consumption	G	0.2	0.1	0.167	[0.050, 0.279
$\theta_{I_G,Y}$	Gvt. investment	G	0.2	0.1	0.216	[0.049, 0.380]
$\theta_{TR,Y}$	Transfers	G	0.2	0.1	0.204	[0.047, 0.353]
$\theta_{W,Y}$	Labour taxes	G	0.5	0.3	0.305	[0.147, 0.456]
$\theta_{K,Y}$	Capital taxes	G	0.5	0.3	0.507	[0.243, 0.771]
$\theta_{C,Y}$	Consumption taxes	G	0.5	0.3	0.356	[0.176, 0.532]

[a] *B - Beta, G - Gamma, IG - Inverse gamma N - Normal*

Table C.1 (cont.): Parameter priors and posterior estimation results

Parameter description		Prior			Posterior	
		Density[a]	Mean	Std. dev	Mean	90% interval
Fiscal policy rules: debt feedback coefficients						
$\theta_{G,B}$	Gvt. consumption	G	0.4	0.2	0.131	[0.062, 0.198]
$\theta_{I_G,B}$	Gvt. investment	G	0.4	0.2	0.554	[0.231, 0.869]
$\theta_{TR,B}$	Transfers	G	0.4	0.2	0.350	[0.010, 0.587]
$\theta_{W,B}$	Labour taxes	G	0.4	0.2	0.162	[0.084, 0.241]
$\theta_{K,B}$	Capital taxes	G	0.4	0.2	0.154	[0.045, 0.256]
$\theta_{C,B}$	Consumption taxes	G	0.4	0.2	0.133	[0.053, 0.213]
Persistence parameters (shock processes)						
ρ_{g_z}	Permanent technology	B	0.85	0.1	0.807	[0.672, 0.994]
ρ_{ε}	Transitory technology	B	0.85	0.1	0.914	[0.845, 0.982]
ρ_i	Investment technology	B	0.85	0.1	0.666	[0.455, 0.883]
ρ_{RP}	Domestic risk premium	B	0.85	0.1	0.926	[0.871, 0.985]
ρ_{RP^*}	Foreign risk premium	B	0.85	0.1	0.993	[0.987, 0.999]
ρ_{ϕ_W}	Wage markup	B	0.85	0.1	0.293	[0.172, 0.417]
ρ_{ϕ_H}	Domestic price markup	B	0.85	0.1	0.437	[0.283, 0.593]
ρ_{ϕ_X}	Export price markup	B	0.85	0.1	0.213	[0.111, 0.305]
ρ_{ϕ^*}	Import price markup	B	0.85	0.1	0.548	[0.275, 0.806]
ρ_G	Gvt. consumption	B	0.85	0.1	0.843	[0.744, 0.942]
ρ_{I_G}	Gvt. investment	B	0.85	0.1	0.829	[0.710, 0.948]
ρ_{TR}	Transfers	B	0.85	0.1	0.508	[0.366, 0.649]
ρ_W	Labour taxes	B	0.85	0.1	0.367	[0.265, 0.469]
ρ_K	Capital taxes	B	0.85	0.1	0.445	[0.318, 0.572]
ρ_C	Consumption taxes	B	0.85	0.1	0.370	[0.265, 0.476]
Structural shocks						
σ_{g_z}	Permanent technology	IG	0.1	2	0.170	[0.105, 0.232]
σ_{ε}	Transitory technology	IG	0.1	2	0.545	[0.414, 0.670]
σ_i	Investment technology	IG	0.1	2	0.417	[0.246, 0.580]
σ_{RP}	Domestic risk premium	IG	0.1	2	0.338	[0.188, 0.485]
σ_{RP^*}	Foreign risk premium	IG	0.1	2	0.363	[0.299, 0.420]
σ_W	Wage markup	IG	0.1	2	0.585	[0.471, 0.692]
σ_H	Domestic price markup	IG	0.1	2	0.468	[0.358, 0.576]
σ_X	Export price markup	IG	0.1	2	4.034	[3.460, 4.588]
σ_*	Import price markup	IG	0.1	2	0.471	[0.272, 0.655]
σ_R	Monetary policy	IG	0.1	2	0.205	[0.177, 0.233]
σ_G	Government consumption	IG	0.1	2	0.554	[0.455, 0.650]
σ_{i_G}	Government investment	IG	0.1	2	3.402	[2.883, 3.917]
σ_{TR}	Transfers	IG	0.1	2	6.590	[5.533, 7.646]
σ_{τ^w}	Labour taxes	IG	0.1	2	0.818	[0.692, 0.944]
σ_{τ^k}	Capital taxes	IG	0.1	2	1.850	[1.559, 2.162]
σ_{τ^c}	Consumption taxes	IG	0.1	2	0.955	[0.793, 1.102]

[a] *B - Beta, G - Gamma, IG - Inverse gamma N - Normal*

Figure C.1: Prior and posterior densities

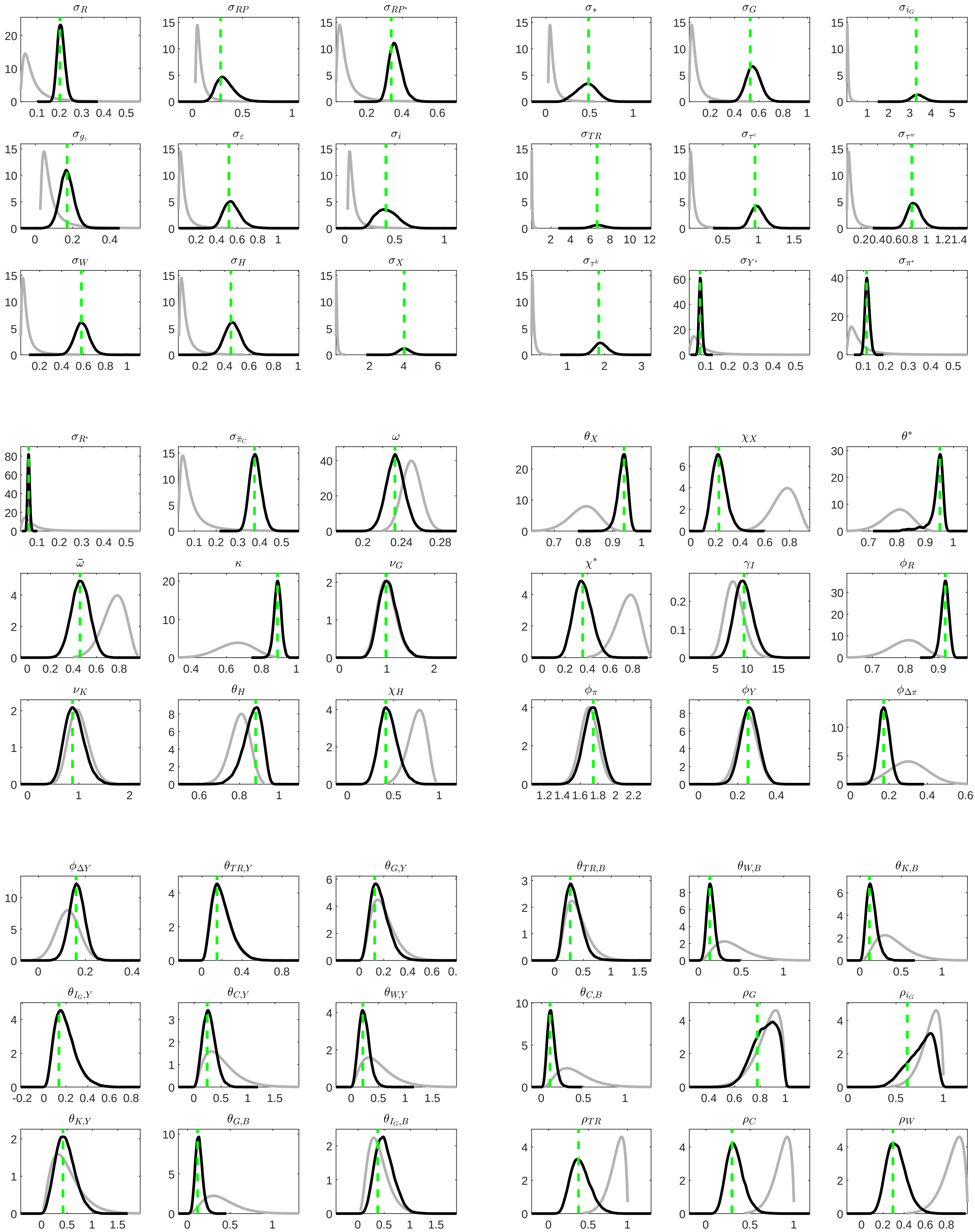


Figure C.1 (cont.): Prior and posterior densities

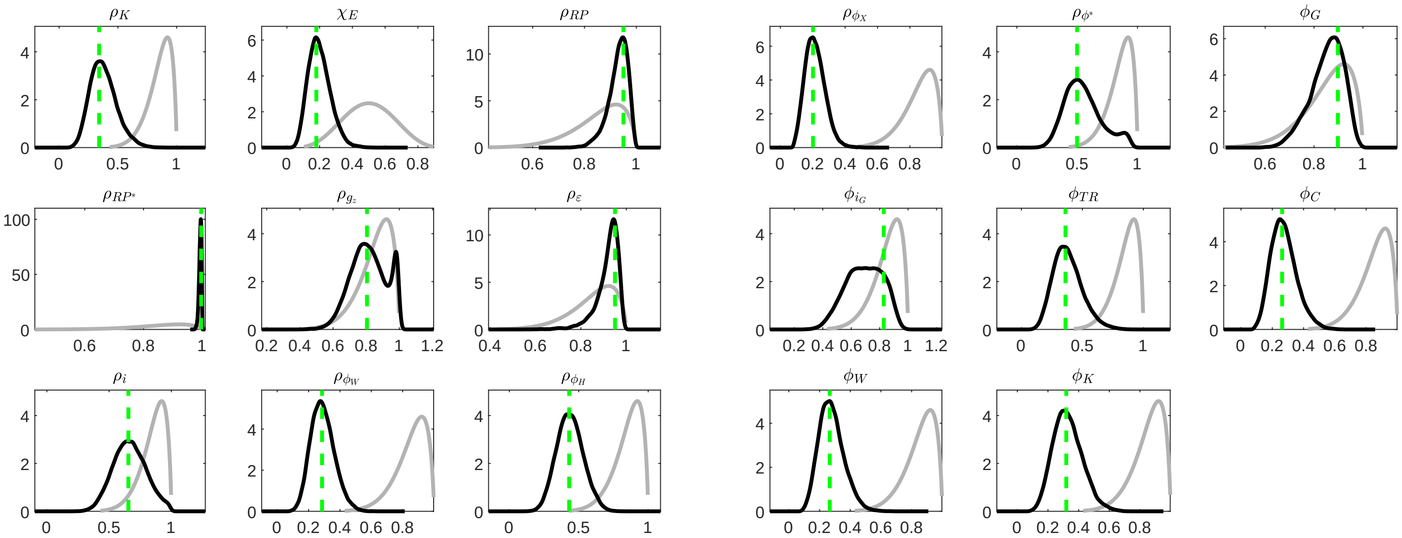


Figure C.2: Identification patterns at posterior mean (lowest singular value)

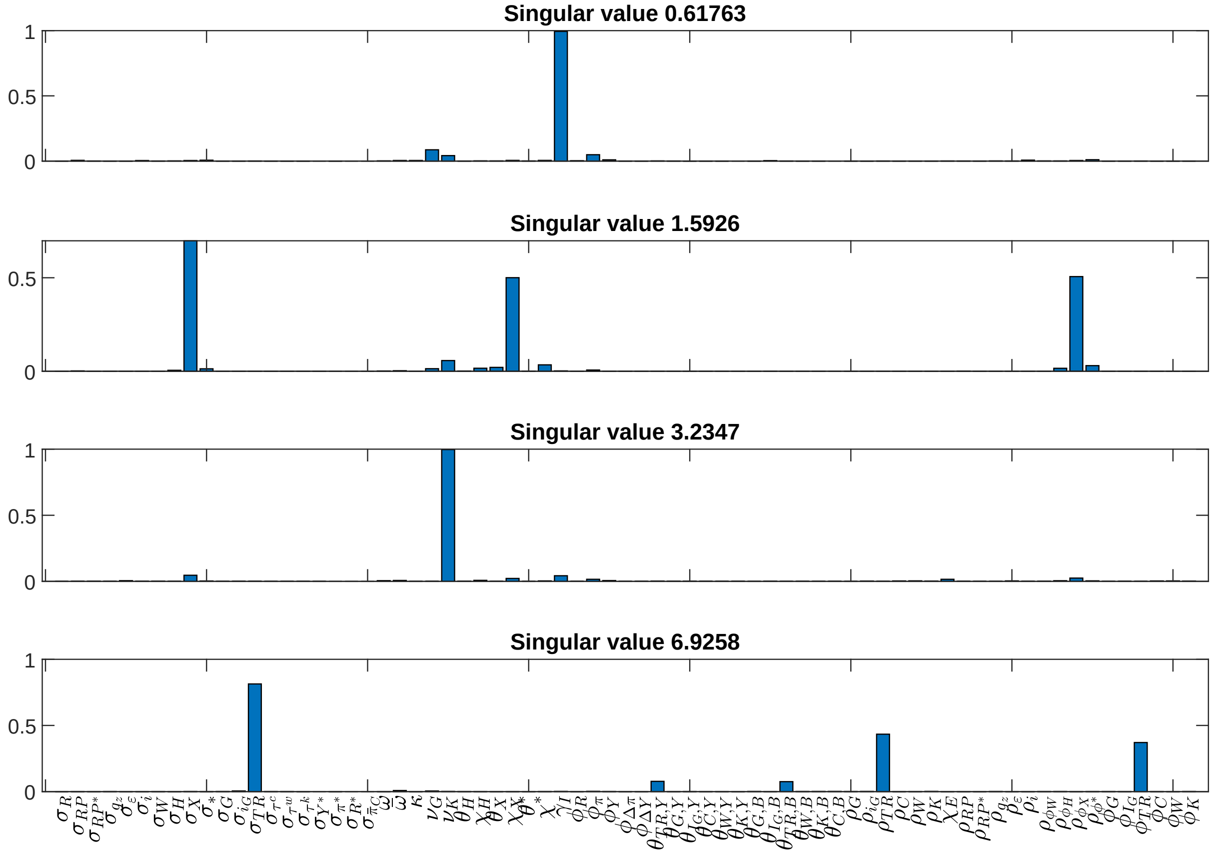


Figure C.3: Identification strength at posterior mean

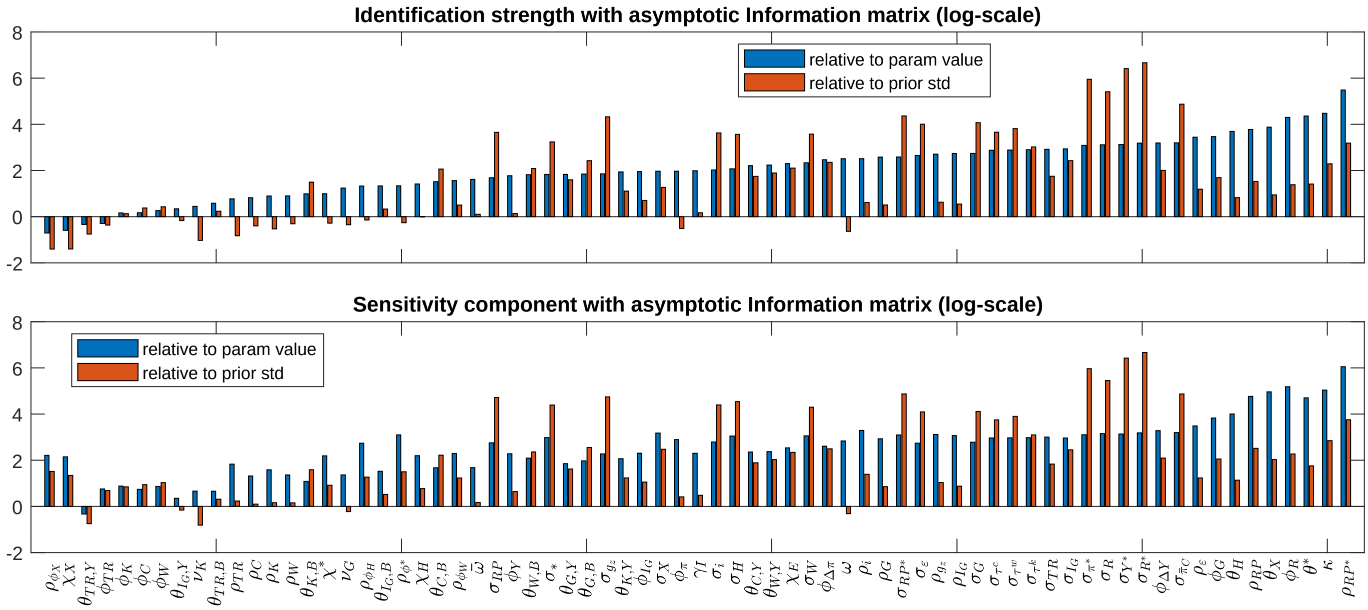


Figure C.4: Sensitivity analysis at posterior mean

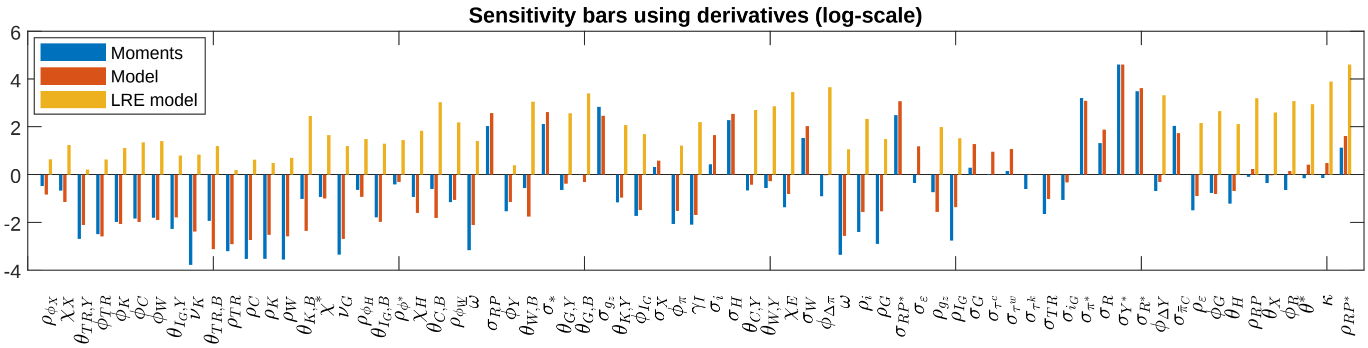
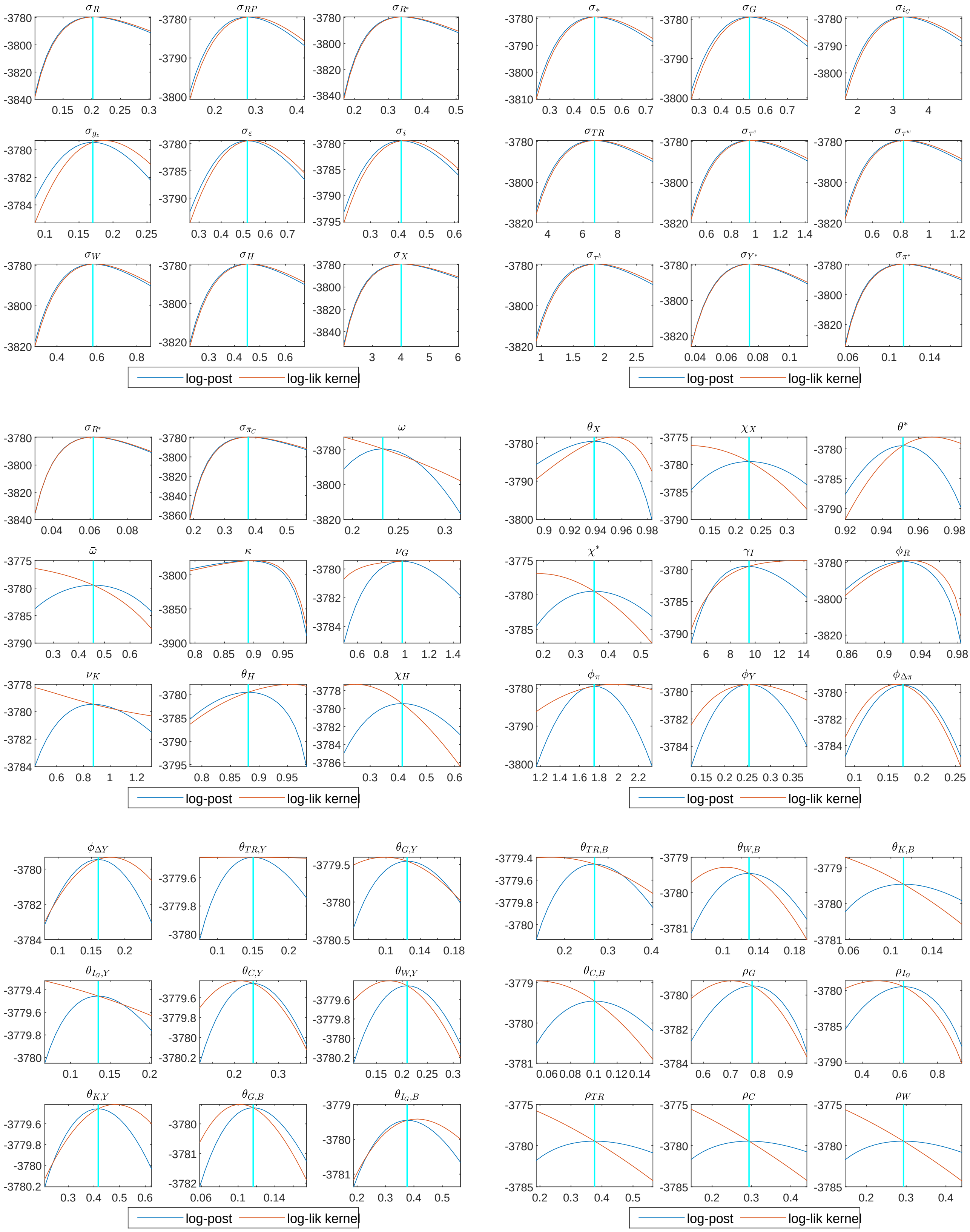
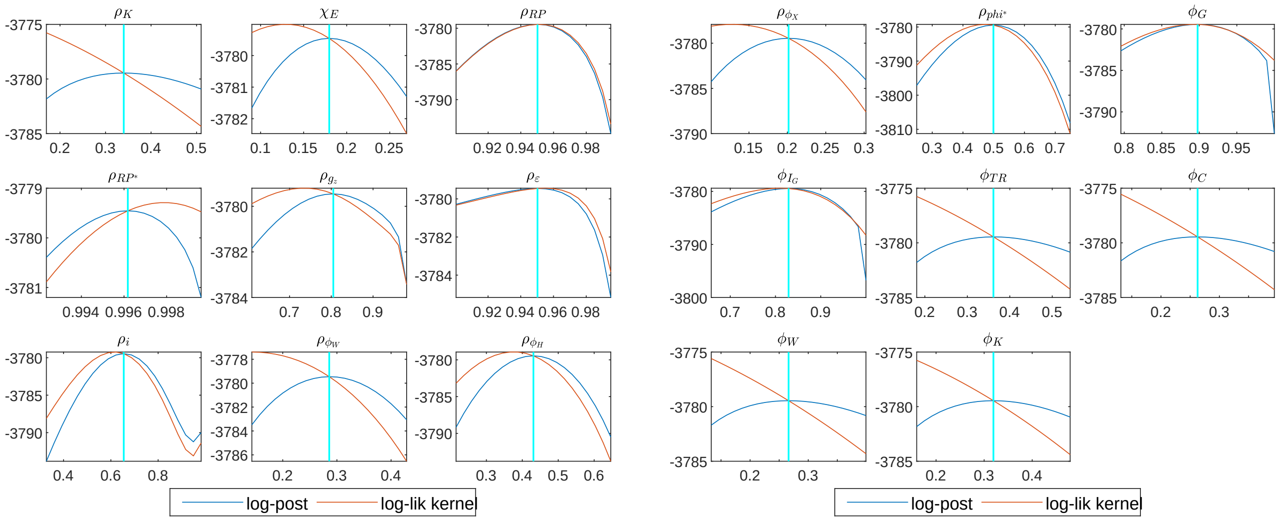


Figure C.5: Log-posterior likelihood functions and log-likelihood kernels



Note: If the estimated mode is the local mode, it should be at the maximum of the posterior likelihood.

Figure C.5 (cont.): Log-posterior likelihood functions and log-likelihood kernels



Note: If the estimated mode is the local mode, it should be at the maximum of the posterior likelihood.

Figure C.6: Multivariate convergence diagnostic

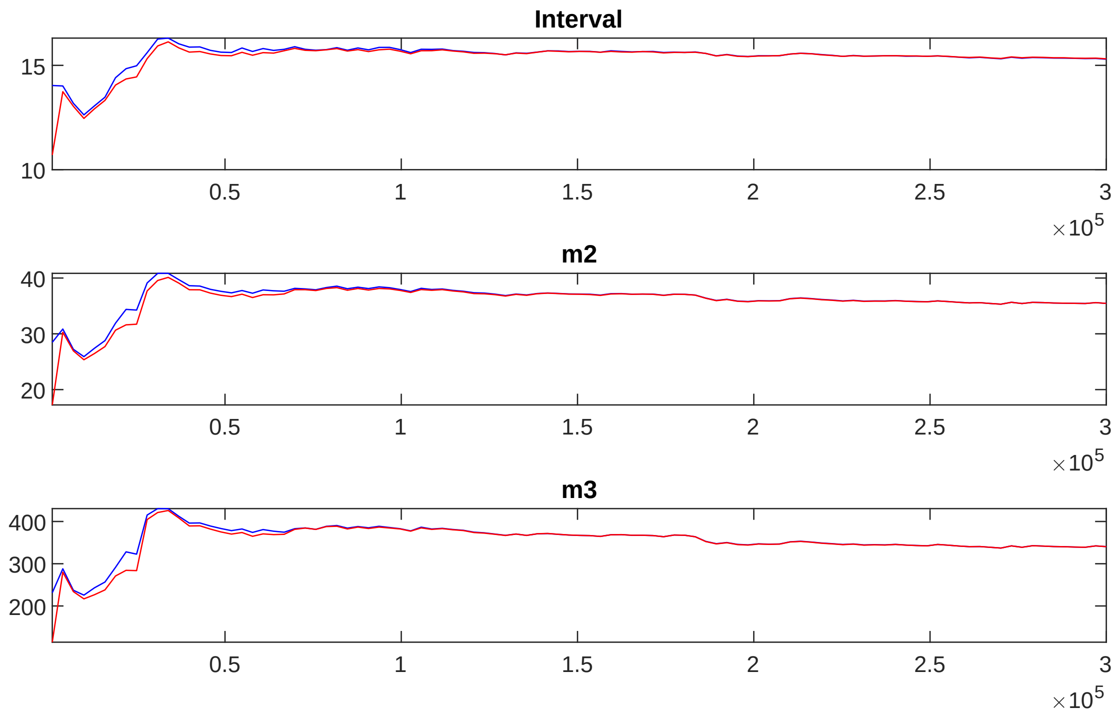


Figure C.7: Univariate convergence diagnostic

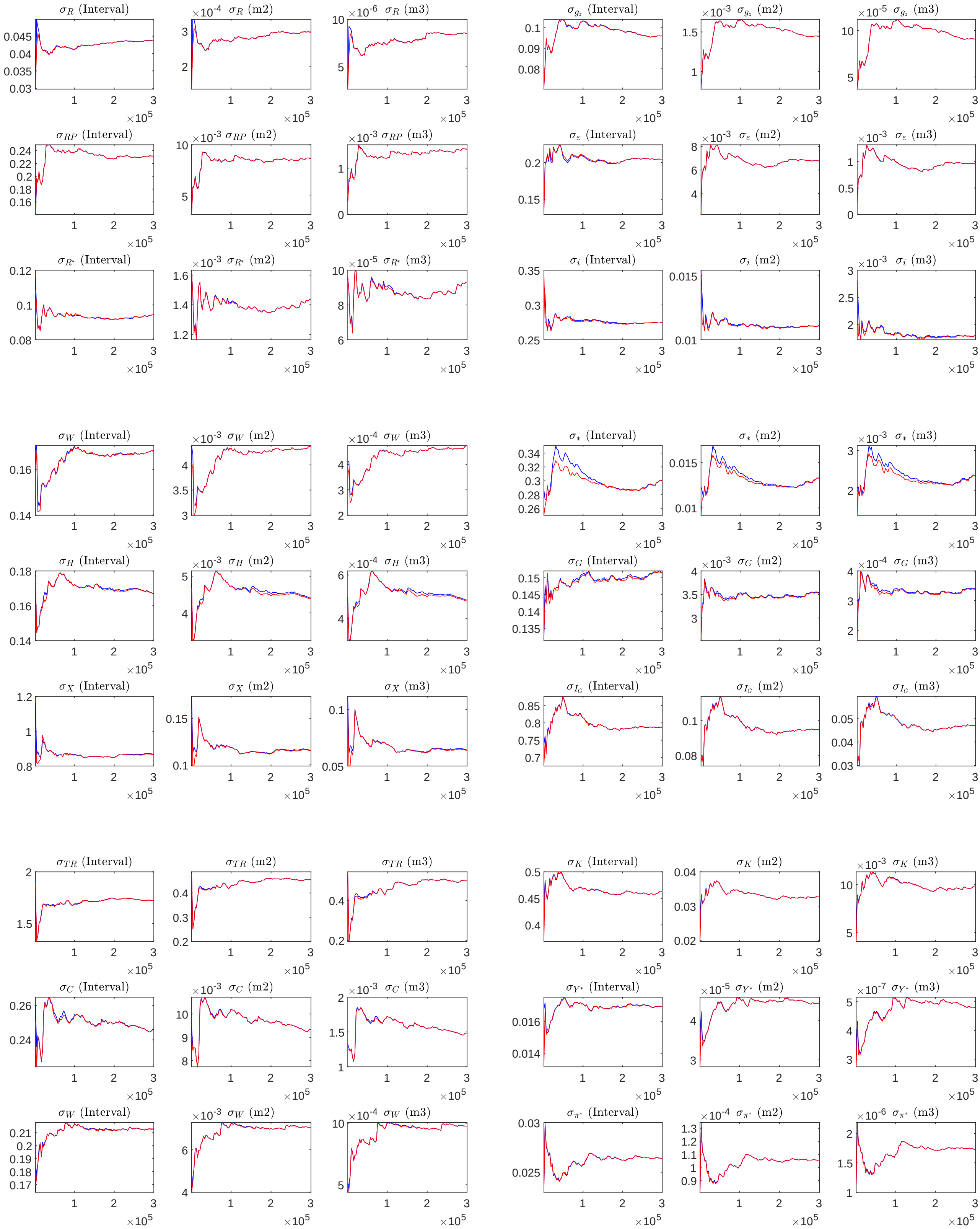


Figure C.7 (cont.): Univariate convergence diagnostic

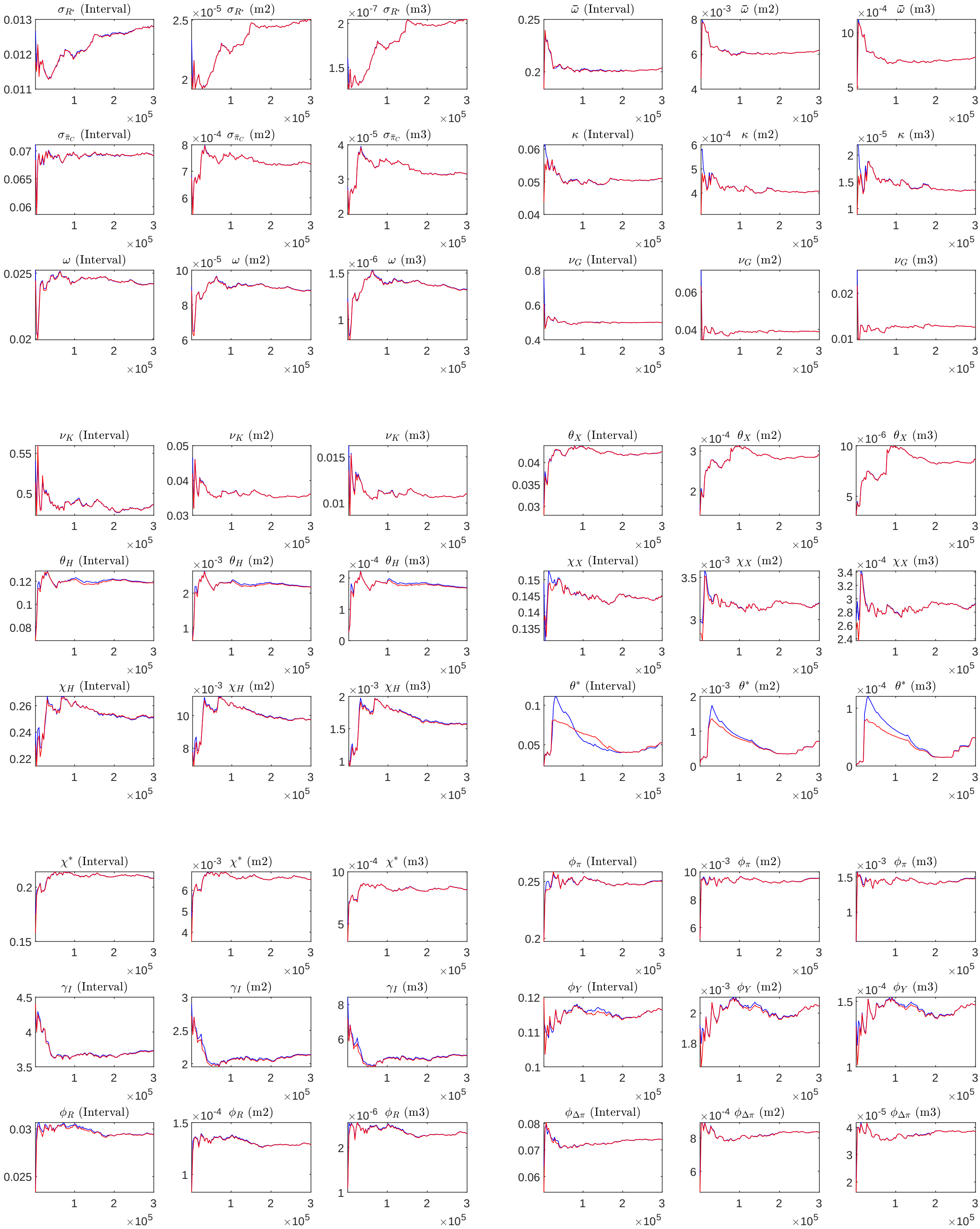


Figure C.7 (cont.): Univariate convergence diagnostic

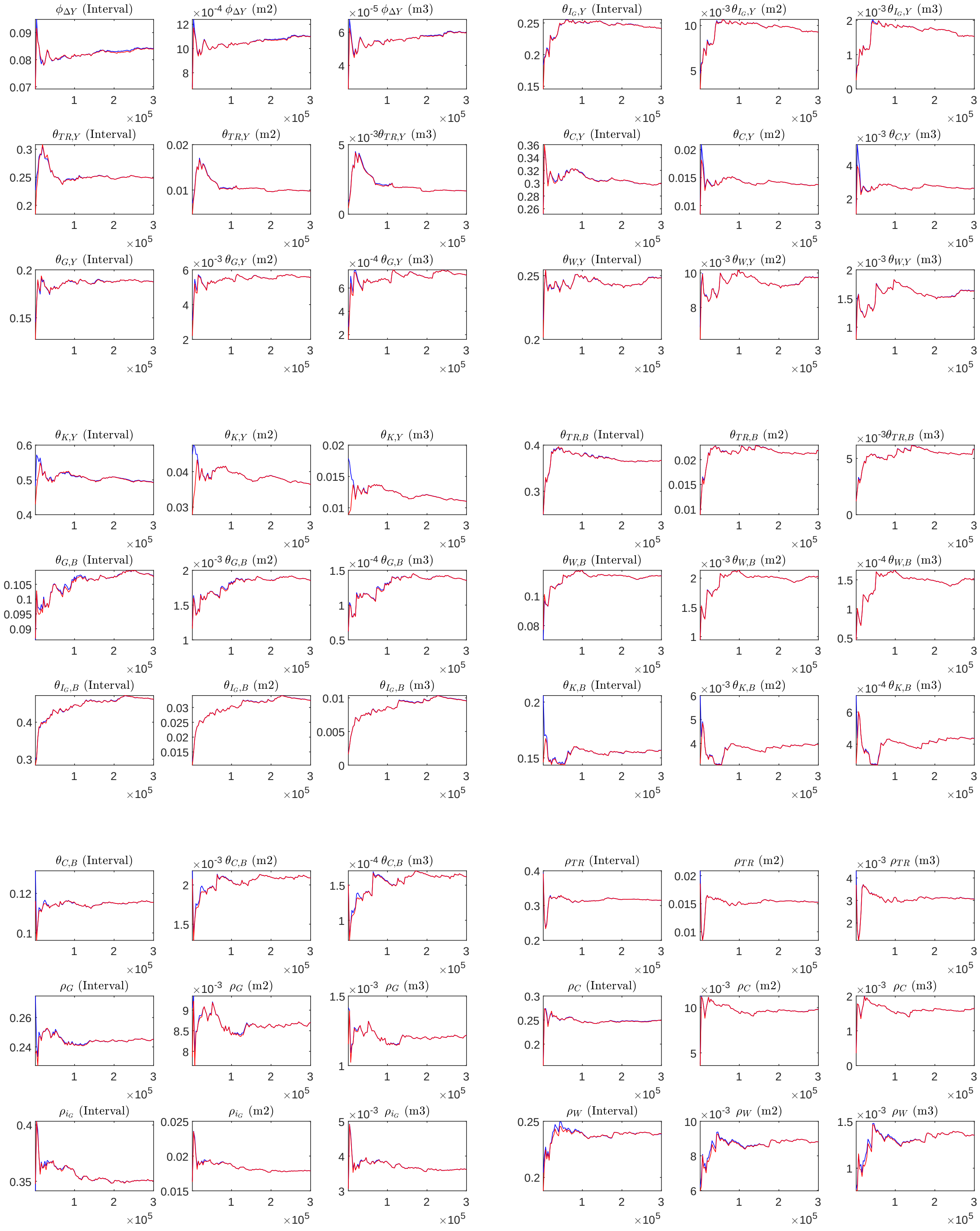


Figure C.7 (cont.): Univariate convergence diagnostic

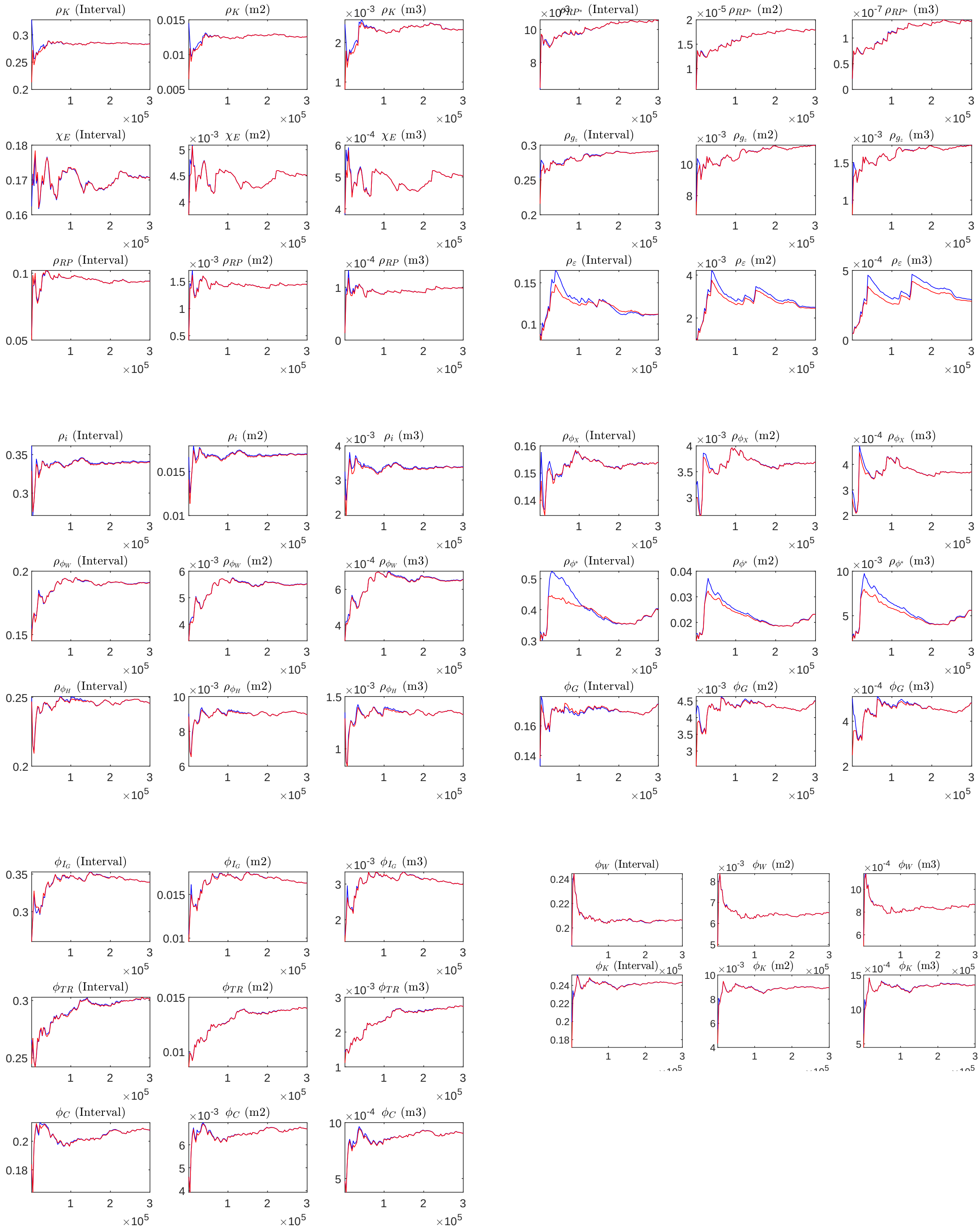


Table C.2: Present-value multipliers: Gvt. spending and investment respond

Variable	Q1	Q4	Q8	Q20	∞
Government consumption multiplier					
$\frac{\Delta Y}{\Delta G}$	0.05	0.26	0.31	0.31	0.29
$\frac{\Delta C}{\Delta G}$	-0.80	-0.67	-0.56	-0.41	-0.39
$\frac{\Delta I}{\Delta G}$	-0.06	-0.08	-0.09	-0.10	-0.09
Government investment multiplier					
$\frac{\Delta Y}{\Delta I_G}$	0.59	0.67	0.64	0.59	0.58
$\frac{\Delta C}{\Delta I_G}$	-0.03	-0.03	-0.03	0.02	0.03
$\frac{\Delta I}{\Delta I_G}$	-0.05	-0.07	-0.08	-0.07	-0.06
Labour tax multiplier					
$\frac{\Delta Y}{\Delta T^w}$	-0.45	-0.39	-0.27	-0.11	-0.09
$\frac{\Delta C}{\Delta T^w}$	-0.63	-0.82	-1.02	-1.19	-1.19
$\frac{\Delta I}{\Delta T^w}$	-0.01	-0.05	-0.11	-0.17	-0.17
Capital tax multiplier					
$\frac{\Delta Y}{\Delta T^k}$	-0.19	-0.14	0.03	0.27	0.29
$\frac{\Delta C}{\Delta T^k}$	-0.04	-0.35	-0.71	-1.07	-1.08
$\frac{\Delta I}{\Delta T^k}$	-0.04	-0.14	-0.26	-0.38	-0.38
Consumption tax multiplier					
$\frac{\Delta Y}{\Delta T^c}$	-0.23	-0.22	-0.09	0.10	0.12
$\frac{\Delta C}{\Delta T^c}$	-0.20	-0.58	-0.91	-1.17	-1.17
$\frac{\Delta I}{\Delta T^c}$	-0.01	-0.07	-0.14	-0.23	-0.23

Table C.3: Present-value multipliers: Taxes respond

Variable	Q1	Q4	Q8	Q20	∞
Government consumption multiplier					
$\frac{\Delta Y}{\Delta G}$	-0.23	0.08	0.14	0.17	0.16
$\frac{\Delta C}{\Delta G}$	-0.87	-0.76	-0.70	-0.63	-0.62
$\frac{\Delta I}{\Delta G}$	-0.09	-0.12	-0.14	-0.17	-0.16
Government investment multiplier					
$\frac{\Delta Y}{\Delta I_G}$	0.48	0.56	0.52	0.48	0.48
$\frac{\Delta C}{\Delta I_G}$	-0.06	-0.11	-0.17	-0.23	-0.23
$\frac{\Delta I}{\Delta I_G}$	-0.06	-0.09	-0.12	-0.14	-0.13
Labour tax multiplier					
$\frac{\Delta Y}{\Delta T^w}$	-0.35	-0.33	-0.32	-0.30	-0.30
$\frac{\Delta C}{\Delta T^w}$	-0.60	-0.58	-0.56	-0.54	-0.53
$\frac{\Delta I}{\Delta T^w}$	0.01	0.03	0.05	0.07	0.07
Capital tax multiplier					
$\frac{\Delta Y}{\Delta T^k}$	-0.04	0.05	0.13	0.20	0.21
$\frac{\Delta C}{\Delta T^k}$	-0.02	0.20	0.38	0.53	0.53
$\frac{\Delta I}{\Delta T^k}$	-0.02	-0.05	-0.08	-0.12	-0.13
Consumption tax multiplier					
$\frac{\Delta Y}{\Delta T^c}$	-0.10	-0.10	-0.08	-0.06	-0.05
$\frac{\Delta C}{\Delta T^c}$	-0.17	-0.19	-0.18	-0.16	-0.15
$\frac{\Delta I}{\Delta T^c}$	0.01	0.03	0.05	0.07	0.07