Essays in Monetary Policy for Emerging Market Economies

A Dissertation

by

Sargam Gupta

November 2019

Thesis submitted to the Indian Statistical Institute in partial fulfillment of the requirements for the degree of Doctor of Philosophy

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To my family and friends

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Chapter 1

Introduction

1.1 Background

The effectiveness of monetary policy in emerging market economies (EMEs) depends on both internal and external factors. Central banks in EMEs have been grappling with volatile capital flows and instability in exchange rates, as a result of unconventional monetary policies adopted by advanced economies (AEs) in the post Global Financial Crisis (GFC) period of 2008-2009 (see Dedola et al. (2017) and Korinek (2018)).[1] Concerns related to the inadequacy of monetary policy in EMEs in stabilizing exchange rates have also been raised in a recent speech delivered by Agustin Carstens at the London School of Economics.[2] Domestically, what makes monetary policy effectiveness challenging in EMEs are factors such as the presence of incomplete financial markets, a distorted agriculture sector and a large informal sector (see Hammond et al. (2009), Ghate and Kletzer (2016)). This dissertation examines the role of monetary policy when specific internal and external disturbances affect the economy. The disturbances are, namely, a procurement distortion in the agriculture sector and high global uncertainty, respectively. The broad message of the dissertation is that the current monetary policy frameworks fol-

[1] Also see Mohan and Kapur (2014) for a discussion on coordinated monetary policy.

[2] Agustin Carstens is a current general manager at BIS and a former governor of Bank of Mexico. Refer to Carstens (2019) for a detailed speech.

lowed by central banks of EMEs are inadequate in offsetting the adverse effects of these disturbances (whether driven by internal or external factors). This dissertation identifies these inadequacies and proposes alternate monetary policy rules which improves welfare of the economy.

Most EMEs including India have a large agriculture sector which are inherently volatile. The share of the agriculture sector as a percentage of GDP between 2011-2015 for EMEs and AEs was 13.4 per cent and 1.8 per cent, respectively (FAO (2017)). A key feature of the agricultural sector in EMEs that prevents an efficient allocation of resources is government induced direct market price support to certain commodities. Market price support estimates (MPSE) in the agriculture sector approximated 2.2 trillion US dollars (between 2011-2015) across the world. Between 2011-2015, out of the total producer support estimates (PSE), the share of MPSE was 55 per cent (OECD (2016*a*)). Further, between 2011-2015, the share of market price support as a percentage of GDP for EMEs was 0.78 per cent, which is almost double the share in AEs, which was 0.40 per cent (OECD (2016*a*)).

In India, the market price support of certain commodities is accompanied by government purchases of the commodity, known as a food procurement policy. Ramaswami et al. (2014) have shown that the accumulated welfare losses of the procurement policy to the Indian economy between 1998 and 2011 was 1.5 billion US dollars. In recent years, rising minimum support prices have fueled food inflation in India (see Anand et al. (2016), Basu (2011), Dev and Rao (2015), Ramaswami et al. (2014), Ghate and Kletzer (2016)). High food inflation is a cause for concern, especially in a developing country like India where food expenditure shares are very high.[3] Chapter 2 of this dissertation discusses the general equilibrium effects of a food policy induced procurement distortion (modelled as a shock) in the agriculture sector on aggregate economy, using a multi-sector new Keynesian-DSGE (Dynamic Stochastic General Equilibrium) model.

[3]For instance, the share of food in consumer expenditure is 52.9 per cent and 42.6 per cent in rural and urban India, respectively (NSS (National Sample Survey) 68^{th} Round $(2011-12)$).

To generate optimal monetary policy rules, a policymaker needs to minimize the welfare loss function for the given economy. Both, strict inflation targeting and flexible inflation targeting rules can be evaluated using the welfare loss function. Chapter 3 of this dissertation derives a welfare loss function for the economy described in Chapter 2. Using the welfare loss function, this chapter discusses the implications of a procurement distortion in the agriculture sector on the *trade-off* between inflation and output gap stabilization under optimal monetary policy rules. Chapters 2 and 3 of this dissertation feature a closed economy and analyze optimal monetary policy in the presence of a real structural challenge present in the agriculture sector of EMEs.

In Chapter 4 of this dissertation, the focus shifts to external factors affecting monetary policy effectiveness. This chapter examines the role of monetary policy in an open economy framework in the presence of uncertainty shocks. There has been a surge in the macroeconomics literature on aggregate uncertainty since the global financial crisis (GFC) of 2008-2009 (see Bloom (2009), Basu and Bundick (2017) and Gourio et al. (2013)). The recent literature has recognized that global uncertainty shocks reduce private consumption and investment sharply in EMEs (see Cespedes and Swallow (2013) and Chatterjee (2018)). This chapter explores the role of exchange rates (both nominal and real) and monetary policy in amplifying/ stabilizing the real effects of global uncertainty shocks in a small open economy framework.

A common aspect in Chapters 2, 3 and 4 is the new Keynesian DSGE framework used for monetary policy analysis. While Chapters 2 and 3 are based on a multi-sector closed economy framework, Chapter 4 is a small open economy model. In both Chapters 3 and 4, a trade-off in inflation and output stabilization is observed with monetary policy rules based on interest rates. As a solution to these trade-offs, Chapter 3 concludes that an optimal simple interest rate rule targeting relative prices or the terms of trade between sectors improves welfare outcome. Chapter 4, however, shows that welfare losses are significantly reduced when a central bank uses the exchange rates as an instrument to implement monetary policy.

The following three sections give an overview of Chapters 2, 3 and 4 of this dissertation.

1.2 Terms of Trade Shocks and Monetary Policy in India

Understanding monetary policy design in emerging markets economies (EMEs) is a growing area of research. One missing aspect in this literature is how distortions in the agriculture sector translate into output and inflation dynamics, and their implications for monetary policy setting. Many developing countries, including India, have a large agriculture sector which is inherently volatile. In India, the combined agriculture sector (agriculture, forestry and fishing) comprised 15 per cent of GDP in 2017-18 (Reserve Bank of India (2018)).[4] The Indian government periodically intervenes in the agricultural sector, especially in the food grain market, by directly procuring grain from farmers to create a buffer grain stock to smooth price volatility and for redistribution to the poor.[5] Non-procured grain becomes available in the market for consumption. By acting like a demand shock in the grain sector, higher procurement increases the market price for grain, because it creates a shortage for open market grain. The procurement also acts like a supply shock as it raises the markup charged by the grain sector firms.

This chapter develops a three-sector (grain, vegetable, and manufacturing) closed economy NK-DSGE model for the Indian economy to understand how one major distortion - the procurement of grain by the government-affects overall inflationary pressures in the economy via changes in the inter-sectoral terms of trade. The basic framework of the model follows, Aoki (2001) and Gali and Monacelli (2005). To model the institutional environment in which procurement takes place in India, we follow Basu (2011)

[4] This is for base year of 2011-2012 at constant prices.

[5] In India, the government through the Food Corporation of India (FCI) procures and stocks food grains, a part of which is released for distribution through the Public Distribution System (PDS) network across the country.

and Anand et al. (2016). We calibrate the model to India.

We show that the general equilibrium effects of a positive procurement shock vary from that of a negative productivity shock. While both shocks lead to aggregate inflation, a one period procurement shock leads to a positive economy-wide output gap while a one period negative productivity shock leads to a slightly negative economy-wide output gap. The transmission of both the shocks from the grain sector to the other sectors also differs. A positive procurement shock is a demand shock in the grain sector which raises the wages in the other sectors. In contrast, a negative productivity shock in the grain sector is a negative supply shock which increases the demand for the other two sector goods and also raises the wages in the other sectors. However, while the procurement shock reallocates labor *away* from the vegetable and the manufacturing sector, a negative productivity shock reallocates labor *towards* the vegetable and the manufacturing sector.

The presence of procurement (under an economically intuitive sufficient condition) changes the standard aggregate NKPC (new Keynesian Phillips curve) and DIS (Dynamic-IS) curves which affects monetary policy design. A positive steady state procurement level makes the aggregate NKPC steeper which means a given output gap is associated with higher inflation compared to the case when there is no procurement. At the same time a positive steady state procurement level affects the economy wide DIS equation and makes the DIS curve steeper. This implies that the response of the real economy to changes in the real interest rate weakens, thus requiring a stronger monetary response to curb inflation, for a given output gap.

1.3 Inefficient Shocks and Optimal Monetary Policy

Most of the literature in monetary policy setting for EMEs focusses on the optimal inflation index that should be targeted to bring the economy close to the flexible-price equilibrium (see Anand et al. (2015), Aoki (2001)). Real disturbances which can be a source of inefficient shocks to these economies, and possibly generate trade-offs between inflation and output gap stabilization for central banks, have not been studied much. In this chapter, we show how market price support policies present in the agriculture sector of EMEs (discussed in Chapter 2) act as a real disturbance leading to such trade-offs.

Using the NK-DSGE model built in Chapter 2, we derive the welfare loss function for a central bank of an economy characterized by the procurement distortion. Although, we build on the NK-DSGE model specific to the Indian economy, the results can also be generalized to other EMEs featuring similar inefficiencies. To derive the welfare loss function we use a micro-founded utility based approach following Rotemberg and Woodford (1997), Rotemberg and Woodford (1999), Woodford (1999) and Woodford (2003). We characterize optimal monetary policy as the welfare loss minimizing policy under discretion and commitment.

We find that the inefficiency due to procurement in the agriculture sector affects the economy through two distinct channels. First, it raises prices in the grain sector by affecting price mark-ups. Second, by reducing aggregate consumption directly, it deprives households of a part of the output. These channels lead to variations in the flexible-price equilibrium which are not efficient. The derived welfare loss function is a function of squares of core-inflation, the consumption gap, and the terms of trade gap, where gaps are not the natural gaps (from the flexible-price equilibrium) but from an efficient equilibrium. For the model economy, an efficient equilibrium with procurement is defined as a flexible-price equilibrium with no mark-up effect of the procurement inefficiency i.e. without the first channel mentioned above.

Optimal monetary policy under discretion and commitment shows that a central bank cannot stabilize core-inflation, output gap and the terms of trade gap simultaneously. This happens due to the presence of procurement inefficiency which makes the flexible price equilibrium of the model economy deviate from its efficient allocation. Thus, any attempt to bring core-inflation to zero makes output deviate from its efficient allocation. This result departs from Aoki (2001), who shows that there exists divine coincidence and welfare losses can be minimized to zero with *strict* core-inflation targeting in EMEs, which features sectoral relative price movements. In other words, our results clearly show that optimal interest rate rules under *strict* core-inflation targeting would be sub-optimal to optimal interest rate rules under *flexible* core-inflation targeting. This result is consistent with Kim and Henderson (2005) who show that interest rate rules for strict inflation targeting regimes are sub-optimal under both full and partial information.

A comparative analysis among different monetary policy rules shows that a commitment interest rate rule leads to the least welfare losses and is thus best among all the considered monetary policy rules. Within the class of implementable monetary policy rules, a simple Taylor rule with target variables only as inflation and the output gap performs the worst. The welfare losses reduce significantly when terms of trade gaps are added to a simple Taylor rule. We also find optimal coefficients on a simple Taylor rule with terms of trade gaps to get an optimal simple rule for the economy. It is observed that an optimal simple rule with sectoral terms of trade/ relative price gaps improves welfare outcomes significantly. We show that welfare losses reduce by 21 per cent and 62 per cent with optimal simple rules for a positive procurement shock and a negative productivity shock, respectively.

1.4 Uncertainty shocks and monetary policy rules in a small open economy

The role of uncertainty shocks in slowing down the real economy and driving business cycles is becoming increasingly recognized in the literature for AEs (see Bloom (2009), Gourio et al. (2013), Bloom et al. (2018), Basu and Bundick (2017) and Ravn and Sterk (2017)). While the literature on the impact of uncertainty shocks on EMEs macroeconomic outcomes is less developed, Fernández-Villaverde et al. (2011) describe how an increase in real interest rate volatility (uncertainty in real interest rates) can have adverse effects on output, consumption and investment. Cespedes and Swallow (2013) argue that global uncertainty shocks adversely impact consumption and investment demand in

EMEs more severely than AEs. Chatterjee (2018) discusses the role of trade openness to explain a disproportionately larger real effects of uncertainty shocks on EMEs compared to AEs.

This chapter explores the role of exchange rates (both nominal and real) and monetary policy in amplifying/ stabilizing the real effects of global uncertainty shocks in a small open (emerging market) economy. Using local projection method, we produce stylized facts from the data to examine the effects of an increase in global uncertainty on macroeconomic variables of EMEs. We build a small open economy NK-DSGE model to qualitatively fit the stylized facts from the data and compare responses of an economy with alternate monetary policy rules. The small open economy is calibrated to a prototypical EME.

The data distinctly shows that exchange rates, both nominal as well real, depreciate strongly in EMEs during periods of high global uncertainty. This happens because capital moves out of EMEs as an immediate response to higher global uncertainty.[6] The consumption demand of a household falls with rise in its savings due to precautionary savings motive. This leads to a fall in the output. Here a depreciating currency in an EME does not lead to an expansion of output, due to expenditure switching, because increasing global uncertainty contracts world output too. Instead, a depreciating currency is contractionary here. This is consistent with the literature emphasizing the contractionary effect of a depreciating currency (see Agenor and Montiel (1999), Cook (2004) and Korinek (2018)).[7]

A currency depreciation also leads to an increase in consumer price inflation in EMEs. A central bank following an interest rate rule (simple Taylor rule), with an inflation stabilization mandate, thus increases the nominal interest rate. An increase in the nominal

[6]This point is also discussed in Fratzscher (2012).

[7]This happens because most of the external debt held by the firms in emerging market economies is denominated in large currencies such as the US dollar. A depreciation (both nominal and real) of currency thus worsens the balances sheet of firms. With worsening balance sheets, foreign investors pull out their funds and firms hit a borrowing/ credit constraint. This can further make things worse if the currency depreciates more with capital moving out of the country.

interest rate can further destabilize a contracting small open economy. Thus, a conventional Taylor type interest rate rule faces a *trade-off* in inflation and output stabilization. To summarize, stabilization of exchange rates is imperative to offset the adverse effects of increasing global uncertainty as interest rate rules fail to do so.

This happens because uncovered interest rate parity (UIP) fails and the link between monetary policy (interest rate rules), exchange rates and the crucial macroeconomic variables of the domestic economy like inflation and output breaks down under uncertainty shocks. UIP fails here because in the presence of global uncertainty, fluctuations in exchange rates are guided by a *hedging motive,* as argued in Benigno et al. (2012). Singh and Subramanian (2008) have shown that the optimal choice of monetary policy instrument depends on the nature of shocks affecting the economy. With global uncertainty shocks we consider nominal exchange rates as an alternate monetary policy instrument in this chapter.

We find that welfare losses are the lowest with exchange rate rules (ERR), followed by a PEG rule.[8] The welfare losses are reduced upto 21 per cent when a central bank switches to following an exchange rate rule from an interest rate rule. A link between monetary policy, exchange rates and key real macro variables like inflation and output is restored with an ERR. Furthermore, the standard deviation of the nominal exchange rate, output and consumer price inflation (CPI) is reduced by 85 per cent, 36 per cent and 45 per cent, respectively, when exchange rate rules are followed instead of interest rate rules. This happens because the risk premium associated with exchange rate rules are lower due to a lower hedging motive.

[8]Heiperzt et al. (2017) also show that exchange rate rules out perform interest rate rules in a small open economy for shocks to the first moment.

Chapter 2

Terms of Trade Shocks and Monetary Policy in India[1]

2.1 Introduction

Understanding monetary policy design in emerging markets and developing economies (EMDEs) is a growing area of research. One missing aspect in this literature is how distortions in the agriculture sector translate into output and inflation dynamics, and their implications for monetary policy setting. In particular, central banks in EMDEs often grapple with understanding the inflationary impact of a shock emanating from the agriculture sector because the precise relationship between aggregate inflation and the terms of trade may be unknown. To address these questions, we develop a three-sector (grain, vegetable, and manufacturing) closed economy NK-DSGE model for the Indian economy to understand how one major distortion - the procurement of grain by the government – affects overall inflationary pressures in the economy via changes in the inter-sectoral terms of trade. Our main contribution is to identify the mechanism through which changes in the terms of trade due to procurement leads to aggregate

[1] This Chapter is a joint work with Chetan Ghate (ISI-Delhi) and Debdulal Mallick (Deakin University), and is published. Refer to Ghate et al. (2018).

inflation, changes in sectoral output gaps, sectoral resource allocation, and the economy wide output gap. We then calibrate the model to India to discuss the role of monetary policy in such a set-up.

Many developing countries, including India, have a large agriculture sector which is inherently volatile. In India, the combined agriculture sector (agriculture, forestry and fishing) comprises 17 per cent of GDP in 2013-14 (Reserve Bank of India (2014)).[2] The employment share of the agriculture sector in India is also large: 47 per cent in 2013-14 (Government of India $(2013-2014)$). The Indian government periodically intervenes in the agricultural sector, especially in the food grain market, by directly procuring grain from farmers to create a buffer grain stock to smooth price volatility and for redistribution to the poor.[3] Non-procured grain becomes available in the market for consumption. By acting like a demand shock in the grain sector, higher procurement increases the market price for grain, because it creates a shortage for open market grain. Procurement also alters the terms of trade between grain and other agricultural goods as well as between agriculture and manufacturing. Changes in the terms of trade have both demand side and supply side effects in the other sectors of the economy thereby affecting economy wide output and inflation dynamics.[4]

The question that arises - for a central bank like the Reserve Bank of India - is how monetary policy should respond to changes in the inter-sectoral terms of trade that stem from a procurement shock. In this chapter, we analyze how a procurement shock transmits through changes in the terms of trade, and affects sectoral wages, marginal costs, sectoral inflation rates, generalized inflation, sectoral output gaps, resource (labor) re-allocation, and ultimately generalized inflation and the economy wide output gap.

We address these issues with a three sector model that has both standard and non-

[2]This is for base year of 2011-2012.

[3]In India, the government through the Food Corporation of India (FCI), procures and stocks food grains, a part of which is released for distribution through the Public Distribution System (PDS) network across the country.

[4]It is worth mentioning that the agriculture sector is also distorted in some way in developed countries, but such distortions may have negligible impacts on the aggregate economy because of a very small share of agriculture in GDP and employment.

standard features. There are four entities in the economy: a representative household, firms, a government, and a central bank. Households consume open market grain, vegetable, and the manufacturing good. They supply labor to all three sectors. Labor is assumed to be perfectly mobile across sectors. The labor market is assumed to be frictionless. The manufacturing sector (M) is characterized by staggered price setting and monopolistic competition. The agricultural sector (A), which is also monopolistically competitive, is disaggregated into a grain (G) and a vegetable (V) sector, both of which are characterized by flexible prices. The reason for this disaggregation in the agriculture sector is to incorporate additional imperfections in the agricultural market that are specific to the Indian economy.

We assume that the grain sector has a procurement distortion, which creates a wedge in the price-setting equation of the firms in the grain market. Procuring grain is distortionary because this leads to a shortage of grain in the open market leading to overall inflationary pressures. In India, as part of the procurement policy, the government announces minimum support prices (MSP) before every cropping season for a variety of agricultural commodities. Minimum support prices are the prices at which a farmer can sell the agricultural commodity to the government, and this is typically set above the market price. The procured grain is then stored in Food Corporation of India (FCI) warehouses, from where a part of it is distributed to poor households. The rest of the procured amount remains in warehouses unconsumed and serves as a buffer stock to offset future supply shocks.

To model the institutional environment in which procurement takes place in India, we follow Basu (2011) and Anand et al. (2016).[5] We assume that consumers purchase grain at the price prevailing in the open market for grain. This price is determined by the supply

[5]Basu (2011), p. 37-38, shows how a distorted food grain market leads to high food inflation and large food grain stocks simultaneously. Anand et al. (2016) discuss the role of the government's buffer stock demand for cereal in increasing food inflation in the Indian economy. Ramaswami et al. (2014) also show how increasing the MSP increases open market prices and fuels food price inflation. They estimate the welfare losses generated from a rising MSP. They find that the accumulated welfare losses amount to 1.5 billion dollars to the Indian economy between 1998-2011.

and the combined demand for grain by consumers and the government for procurement. In Figure 2-1, this is represented by the total demand for grain schedule, PP. The demand for grain by consumers is given by the schedule, OO. A positive procurement shock leads to an increase in the total demand for grain, which shifts the demand schedule outward from OO to PP. The increase in demand leads to a change in the market equilibrium from point X to Z. The open market price rises from P^* to P_{OG}, where the new market clearing price, P_{OG}, is equal to the MSP. At P_{OG}, the supply of grain increases from OE to OA. However, the open market grain left for the consumer reduces from OE to OB, with the rest of the grain, AB, procured. A farmer sells the quantity, AB, to the government at the MSP (or at P_{OG} in our model as explained above). Thus, a procurement shock acts like a demand shock in the grain sector, which leads to a higher open market grain price and a lower open market grain quantity. However, the government stops purchasing grain once it meets its targeted amount. We later show that a shock to the public procurement of grain because of an increase in the demand for grain is equivalent to a time varying mark-up shock in the grain sector, i.e., higher procurement raises the mark-up charged by grain sector firms. Procurement therefore acts like a tax on grain consumers.

[INSERT FIGURE 2-1]

To close the model, the central bank implements monetary policy via a simple Taylor-style interest rate rule.

2.1.1 Main Results

The theoretical contribution of our paper is to provide a rigorous understanding of the general equilibrium effects of procurement shocks using a closed economy NK-DSGE model. In particular, we seek to uncover the transmission mechanism of a positive procurement shock and a negative productivity shock on output and inflation dynamics, and compare their implications for monetary policy design for the Reserve bank of India and other emerging market central banks. We consider these two cases because they typify the kind of shocks experienced by the Indian agriculture sector such as an upward increase in procurement (positive procurement shock) or a bad monsoon (negative productivity shock).

Procurement Shock

On impact, a one period positive procurement shock increases the price of open market grain. This increases the terms of trade i) between grain and vegetable (intra-sectoral terms of trade), and ii) between the agriculture sector and the manufacturing sector (inter-sectoral terms of trade), making other sectoral goods (vegetable and manufacturing) relatively cheaper. Also, a procurement shock immediately raises the demand for labor in the grain sector leading to higher nominal wages in the labor market since the grain sector pulls labor away from other sectors. Because labor is mobile across sectors, nominal wages increase and equalize in all the sectors. The vegetable and manufacturing sector firms raise the prices of their goods in response to higher nominal wages, leading to generalized inflation.

Moreover, the manufacturing sector is a sticky price sector and thus only a fraction of firms revise their prices and this creates a positive output gap on impact. As a response to the rise in inflation and positive output gap the central bank raises the nominal interest rate. The real interest rate, which is the nominal interest rate adjusted for one period ahead expected inflation, also rises. A rise in the real interest rate induces a fall in aggregate consumption because of the inter-temporal substitution effect. From the aggregate goods market clearing condition, this would imply that the output produced for consumption (non-procured grain, vegetable, and manufactured goods) will fall. However, because the rise in procured output *exceeds* the reduction in output produced for consumption, *aggregate* output increases.

On impact, from the demand side, the reduction in consumption is consistent with a reduction in the sectoral demand for goods. The income effect reduces proportionately the demand for each sectoral good because aggregate consumption falls and sectoral demands are proportionate to aggregate consumption. On the other hand the substitution effect induces an increase in the demand for the manufacturing and the vegetable sector goods as both are now relatively cheaper compared to grain. In the net, the income effect dominates the substitution effect. Moreover, due to sectoral goods market clearing, the lower sectoral demand for manufacturing, open market grain, and vegetable, leads to less labor employed in these sectors. However, because aggregate output increases, lower employment in the open market grain (OG) sector, the manufacturing (M) sector, and the vegetable (V) sector, is more than offset by an increase in labor demand for producing procured grain (PG). Therefore total employment rises. Over time, the real interest rate falls back to its long run value, and consumption rises back to its steady state value. Hence, output approaches its steady state and the output gap goes to zero. As the effect of the procurement shock dampens, the real wage falls over time back to its steady state value, and the sectoral consumption shares, sectoral employment shares, and the intra-sectoral and inter-sectoral terms of trade fully adjust to their original pre-procurement shock levels.

In sum, a one period positive procurement shock leads to aggregate inflation, a positive output gap and labor reallocation away from the manufacturing and the vegetable sectors.

Productivity Shock

On impact, a one period negative productivity shock decreases grain output and increases grain prices. This increases the terms of trade i) between grain and vegetable (intra-sectoral terms of trade), and ii) between the agriculture sector and the manufacturing sector (inter-sectoral terms of trade), making other sectoral goods (vegetable and manufacturing) relatively cheaper. The demand for vegetable and manufacturing sector goods increases. The vegetable and manufacturing sector goods firms respond to this by increasing their output, which increases their demand for labor. A higher demand for labor in these two sectors leads to higher nominal wages across the economy. The vegetable and manufacturing sector firms raise the prices of their goods in response to higher nominal wages, leading to generalized inflation.

Moreover, the manufacturing sector is a sticky price sector and thus only a fraction of firms revise their prices and this creates a negative output gap on impact. At the same time the economy wide output gap also falls slightly. Monetary policy responds to this increase in inflation and slightly negative output gap by an increase in the nominal interest rate. The real interest rate rises. A rise in the real interest rate induces a fall in aggregate consumption because of the inter-temporal substitution effect.

On impact, from the demand side, the reduction in consumption is consistent with a increase in the sectoral demand for goods (vegetable and manufacturing) because the substitution effect due to the increase in the intra-sectoral and inter-sectoral terms of trade offsets the income effect due to a downward reduction in consumption. The income effect reduces the demand for each sectoral good. On the other hand the substitution effect increases the demand for the manufacturing and the vegetable sector goods as both are relatively cheaper. Because of sectoral goods market clearing, the higher sectoral demand for manufacturing and vegetable leads to more employment in these sectors. As the effect of the productivity shock dampens, the nominal wage falls over time back to its steady state value, and the sectoral consumption shares, sectoral employment shares, and the intra-sectoral and inter-sectoral terms of trade fully adjust to their original pre-shock levels. In sum, a one period negative productivity shock leads to aggregate inflation, a slightly negative output gap and labor reallocation towards the manufacturing and the vegetable sectors.

Comparison between both shocks

While we observe that both the shocks lead to sectoral and general inflation, Table 2.1 below summarizes the differences in the two shocks.

One time positive procurement shock	One time negative productivity shock
1) Increases grain sector output.	1) Decreases grain sector output.
2) Acts as a negative cost push shock to the other two sectors.	2) Acts as a positive demand shock to the other two sectors.
3) Leads to a positive output gap.	3) Leads to a slightly negative output gap.
4) Labor reallocation away from the manufacturing and vegetable sectors.	4) Labor reallocation towards the manufacturing and vegetable sectors.

Table 2.1: Main differences between a one period positive procurement shock and a one period negative productivity shock

When we calibrate the model to Indian data we show that, higher is the share of the household's expenditure on the agricultural sector good, higher is the impact on inflation from both shocks.

NKPC and DIS Equations

We show that the presence of procurement (under an economically intuitive sufficient condition) changes the aggregate NKPC and DIS curves which affects monetary policy design. A positive steady state procurement level makes the aggregate NKPC steeper which means a given output gap is associated with higher inflation compared to the case when there is no procurement. At the same time a positive steady state procurement level affects the economy wide DIS equation and makes the DIS curve steeper. This implies that the response of the real economy to changes in the real interest rate becomes less strong, thus requiring a stronger monetary response to curb inflation, for a given output gap. This happens because procurement creates a wedge between the output produced and the output consumed. The changes in the real rate of interest affects only output consumed which is a constant proportion of total output. Hence, procurement weakens monetary policy transmission since monetary policy only affects consumed output. Moreover, a positive steady state procurement level distorts the steady state level of all the endogenous variables which makes aggregate inflation higher and the economy-wide output gap higher. Since monetary policy follows a simple Taylor rule in our model, monetary policy is directly affected by the government's procurement policy.

2.1.2 Literature Review

Our model is most closely related to the seminal work by Gali and Monacelli (2005) and Aoki (2001). The main difference between our model and these papers is that Gali and Monacelli have an open economy set-up while our model assumes a closed economy. In terms of Aoki (2001), while he does not model procurement, in his two sector model, the flexible price sector (the food sector) is distortion free, while in our model the flexible price sectors are not distortion-free. However, similar to Aoki (2001) we explain the transmission of inflation from a shock in the flexible sector to the other sectors because of a change in the terms of trade.[6] Our paper also discusses reasons behind the labor allocation induced in the economy due to these shocks which is not a focus in Aoki (2001). In our framework, a grain sector shock not only shifts the aggregate NKPC (as in Aoki (2001)), but it also changes the slope of the NKPC. In particular, we show that procurement leads to a steepening of the NKPC and DIS curve under a sufficient condition. The procurement distortion therefore affects the responsiveness of the economy to changes in the interest rate which affects the monetary policy response.

A multi-sector model with different sectors has the advantage of allowing one to understand the transmission of sectoral shocks across the economy. A multi-sector setting affects the design of monetary policy depending on the presence of sectoral nominal rigidities and frictions (see Aoki (2001), Benigno (2004), Huang and Liu (2005) and Erceg

[6] Aoki (2001) explains the transmission of inflationary pressures in an economy from a flexible price sector to sticky price sector which leads to generalized inflation.

and Levin (2006)). Importantly, shocks in a multi-sector setting affect relative prices or the terms of trade which have real affects on the economy. Our paper is different from the above papers as much of the literature on terms of trade shocks in multi-sector settings assume a small open economy set-up (see Hove et al. (2015), Ortega and Rebei (2006), Carlos et al. (2010)). Although terms of trade shocks in an open economy set-up are important, inter-sectoral terms of trade shocks are also a key concern of monetary policy setting in emerging and developing economies.

2.2 The Model

There are four entities in the economy: a representative household, firms, the government, and a central bank. Households consume open market grain, vegetable, and the manufacturing good. They supply labor to all three sectors. Labor is assumed to be perfectly mobile across sectors. The labor market is assumed to be frictionless. There is a manufacturing sector (M) – which is characterized by staggered price setting and monopolistic competition – and an agricultural sector (A). The agricultural sector, which is also monopolistically competitive, is further disaggregated into a grain (G) and a vegetable (V) sector, which are both characterized by flexible prices. The government sector procures grain. The central bank sets the short term interest rate using a Taylor (1993) style rule. We discuss each sector in detail.[7]

2.2.1 Households

An infinitely lived household gets utility from a consumption stream, C_t, and disutility from labor supply, N_t. At time 0, the household maximizes its expected lifetime utility,

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[U(\Gamma_t C_t) - V(N_t) \right], \tag{2.1}$$

[7]Derivations for the entire model are in the Technical Appendix A.1.

where $\beta \in (0,1)$ is the discount factor, and Γ_t is the preference induced demand shock which is assumed to be the same across households and follows an AR(1) process. The utility function is standard and specified as:

$$U(\Gamma_t C_t) \equiv \frac{(\Gamma_t C_t)^{1-\sigma}}{1-\sigma} \tag{2.2}$$

$$V(N_t) \equiv \frac{(N_t)^{1+\psi}}{1+\psi} \tag{2.3}$$

where, σ, is the inverse of the inter-temporal elasticity of substitution and, ψ, is the inverse of the Frisch elasticity of labor supply. Aggregate consumption, C_t, is a composite Cobb-Douglas index of consumption of manufacturing, $C_{M,t}$, and agriculture sector goods, $C_{A,t}$, and is defined as:

$$C_t \equiv \frac{(C_{A,t})^{\delta}(C_{M,t})^{1-\delta}}{\delta^{\delta}(1-\delta)^{(1-\delta)}}, \qquad 0 < \delta < 1, \tag{2.4}$$

where δ is the share of total consumption expenditure allocated to agriculture sector goods. Agricultural goods, $C_{A,t}$, is again a composite Cobb-Douglas index of consumption of grain bought by the consumers in the open market, $C_{OG,t}$, and vegetable, $C_{V,t}$, and is defined as:

$$C_{A,t} \equiv \frac{(C_{V,t})^{\mu}(C_{OG,t})^{1-\mu}}{\mu^{\mu}(1-\mu)^{(1-\mu)}}, \qquad 0 < \mu < 1, \tag{2.5}$$

with μ being the share of total food expenditure allocated to vegetable sector goods. Consumption in each of the three sectors, $C_{M,t}$, $C_{OG,t}$ and $C_{V,t}$ is a CES aggregate of a continuum of differentiated goods in the respective sector indexed by $j \in [0,1]$: $C_{M,t} \equiv \left(\int_0^1 C_{M,t}(j)^{\frac{\theta-1}{\theta}} dj\right)^{\frac{\theta}{\theta-1}}$; $C_{OG,t} \equiv \left(\int_0^1 C_{OG,t}(j)^{\frac{\theta-1}{\theta}} dj\right)^{\frac{\theta}{\theta-1}}$ and $C_{V,t} \equiv \left(\int_0^1 C_{V,t}(j)^{\frac{\theta-1}{\theta}} dj\right)^{\frac{\theta}{\theta-1}}$, where $\theta > 1$ is the elasticity of substitution between the varieties within each sector and is assumed to be the same in all sectors.

Each household maximizes its lifetime utility given by equation (2.1) subject to an inter-temporal budget constraint

$$\int_0^1 P_{OG,t}(j)C_{OG,t}(j)dj + \int_0^1 P_{V,t}(j)C_{V,t}(j)dj + \int_0^1 P_{M,t}(j)C_{M,t}(j)dj$$

$$+ \ E_t\{Q_{t,t+1}B_{t+1}\} \leqslant B_t + W_t N_t - T_t + Div_t \tag{2.6}$$

where $P_{s,t}(j)$ is the price of variety j in sector $s = OG, V$, and M. B_{t+1} is the nominal pay-off in period $t+1$ of the bond held at the end of period t. $Q_{t,t+1}$ is the stochastic discount factor. The transversality condition, $\lim_{T\to\infty} E_t\{B_t\} \geq 0 \quad \forall\ t$, is assumed to be satisfied. W_t is the economy wide nominal wage rate. T_t are lump-sum taxes to the government, and Div_t are the dividends or profits distributed to households by monopolistically competitive firms. Money is excluded from both the budget constraint and utility function as the demand for money is endogenized.

Optimal consumption expenditure allocations are given as solutions to maximizing the composite consumption index subject to a given level of expenditure level. For the agricultural and manufacturing goods, the optimal allocations are:[8]

$$C_{A,t} = \delta \left(\frac{P_{A,t}}{P_t}\right)^{-1} C_t \tag{2.7}$$

$$C_{M,t} = (1-\delta) \left(\frac{P_{M,t}}{P_t}\right)^{-1} C_t \tag{2.8}$$

where the aggregate price index for the economy, or equivalently the consumer price index (CPI), is $P_t \equiv (P_{A,t})^{\delta}(P_{M,t})^{1-\delta}$ with $P_{A,t}$ and $P_{M,t}$ being the prices of the composite agricultural and manufacturing goods, respectively. Similarly, the optimal allocations of open market grain and vegetable are given by,

$$C_{OG,t} = (1-\mu) \left(\frac{P_{OG,t}}{P_{A,t}}\right)^{-1} C_{A,t} \tag{2.9}$$

$$C_{V,t} = \mu \left(\frac{P_{V,t}}{P_{A,t}}\right)^{-1} C_{A,t}, \tag{2.10}$$

respectively, where the price of agricultural goods is given by, $P_{A,t} \equiv (P_{V,t})^{\mu}(P_{OG,t})^{1-\mu}$. Finally, the optimal allocation within each category of goods give the following demand

[8] For details, refer to the Technical Appendix A.1.

functions for the j^{th} variety in the sector s:

$$C_{s,t}(j) = \left(\frac{P_{s,t}(j)}{P_{s,t}}\right)^{-\theta} C_{s,t} \quad \text{for all } j \in [0,1] \tag{2.11}$$

for $s = OG, V$, and M, and $P_{s,t} \equiv \left(\int_0^1 P_{s,t}(j)^{1-\theta} dj\right)^{\frac{1}{1-\theta}}$ is the sector $'s'$ specific price index.

Combining equations (2.7)−(2.11), it is straightforward to show that $\int_0^1 P_{OG,t}(j)C_{OG,t}(j)dj + \int_0^1 P_{V,t}(j)C_{V,t}(j)dj + \int_0^1 P_{M,t}(j)C_{M,t}(j)dj = P_tC_t$. Therefore, the budget constraint equation(2.6) can be rewritten as

$$P_tC_t + E_t\{Q_{t,t+1}B_{t+1}\} \leqslant B_t + W_tN_t - T_t + Div_t \ . \tag{2.12}$$

The solution to maximizing (2.1) subject to (2.12) yields the following optimality conditions:

$$E_t\left[\beta R_t \left(\frac{\Gamma_{t+1}}{\Gamma_t}\right)^{1-\sigma} \left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} \frac{P_t}{P_{t+1}}\right] = 1 \tag{2.13}$$

$$\frac{(N_t)^{\psi}}{(\Gamma_t)^{1-\sigma}(C_t)^{-\sigma}} = \frac{W_t}{P_t} \tag{2.14}$$

where $R_t = \frac{1}{E_t\{Q_{t,t+1}\}}$ is the gross nominal return on the riskless one-period bond. Equation (2.13) is the Euler equation. Equation (2.14) is the optimal labor supply equation.

2.2.2 Terms of Trade: Some Useful Identities

Before proceeding further, we introduce several definitions and identities that will be used in the rest of the paper. CPI inflation is the change in the aggregate price index and is given by $\pi_t = \ln P_t - \ln P_{t-1}$. Using the definition of the aggregate price index, CPI inflation can be expressed as a weighted average of sectoral inflation rates: $\pi_t = \delta\pi_{A,t} + (1-\delta)\pi_{M,t}$, where $\pi_{A,t}$ and $\pi_{M,t}$ are inflation in the agricultural and manufacturing goods prices, respectively. Similarly, inflation in the agricultural goods prices can be further disaggregated as the weighted average of inflation in the grain and vegetable prices ($\pi_{OG,t}$ and $\pi_{V,t}$, respectively): $\pi_{A,t} = (1-\mu)\pi_{OG,t} + \mu\pi_{V,t}$. Therefore, CPI inflation can be expressed in terms of sectoral inflation rates as:

$$\pi_t = \delta(1-\mu)\pi_{OG,t} + \delta\mu\pi_{V,t} + (1-\delta)\pi_{M,t}. \tag{2.15}$$

Defining the terms of trade (TOT) between agriculture and manufacturing (inter-sectoral), and also between grain and vegetable within the agricultural sector (intra-sectoral) is important because of their role in influencing aggregate output and inflation dynamics. We define the inter-sectoral TOT as

$$T_{AM,t} \equiv \frac{P_{A,t}}{P_{M,t}}, \tag{2.16}$$

and the intra-sectoral TOT as

$$T_{OGV,t} \equiv \frac{P_{OG,t}}{P_{V,t}}. \tag{2.17}$$

Equations (2.16) and (2.17) reveal that changes in the TOT can be expressed in terms of sectoral inflation rates:[9]

$$\Delta\widehat{T}_{AM,t} = \pi_{A,t} - \pi_{M,t} \tag{2.18}$$

and

$$\Delta\widehat{T}_{OGV,t} = \pi_{OG,t} - \pi_{V,t}. \tag{2.19}$$

Combining equations (2.15) with (2.18) and (2.19), CPI inflation dynamics can be shown to be directly related to the inter-sectoral TOT and intra-sectoral TOT. This is given by

$$\pi_t = \pi_{OG,t} - \mu\Delta\widehat{T}_{OGV,t} - (1-\delta)\Delta\widehat{T}_{AM,t}. \tag{2.20}$$

[9]Variable $\widehat{X}_t$, is the log-deviation from steady state and is defined as,

$$\widehat{X}_t = \ln X_t - \ln X$$

The interpretation of equation (2.20) is the same as equation (2.15). Deteriorations of both the intra-sectoral TOT (i.e., higher inflation in vegetable relative to open grain), and inter-sectoral TOT (i.e., higher inflation in manufacturing relative to agriculture) increase CPI inflation. It will be shown later that these changes in the terms of trade alter resource allocation across sectors thus playing a critical role for the sectoral allocation of resources in the economy.

2.2.3 Firms

In our model, while firms in the three sectors differ only in their price setting behavior, they are similar in terms of their production technology and market structure. All three markets are monopolistically competitive. Prices in both the grain and vegetable sectors are fully flexible, while in the manufacturing sector prices are set in a staggered fashion as outlined below. Crucially, as mentioned in the introduction, the grain sector differs from the vegetable sector due to the government procurement of grain. Our model departs crucially from Aoki (2001) in this respect as the agriculture sector in Aoki (2001) is characterized both by flexible prices and perfect competition.

We assume that in each sector, s, there are a continuum of firms indexed by $j \in [0, 1]$. Each firm produces a differentiated good using, $N_{s,t}(j)$, units of labor:

$$Y_{s,t}(j) = A_{s,t} N_{s,t}(j), \tag{2.21}$$

for $s = G, V$ and M. Here, $A_{s,t}$, is the sector-specific level of technology and its (log) first-difference follows an AR(1) process, i.e., $\Delta \ln A_{s,t} = \rho_s \Delta \ln A_{s,t-1} + \epsilon_{s,t}$. The nominal marginal cost of production in sector s is given by,

$$MC_{s,t} = \frac{W_t}{MPN_{s,t}} = \frac{W_t}{A_{s,t}}, \tag{2.22}$$

where $MPN_{s,t}$ is the marginal product of labor in sector s, where $s = G$, V and M. Using the definitions of the terms of trade, the sectoral real marginal cost $\left(mc_{s,t} = \frac{MC_{s,t}}{P_{s,t}}\right)$ for the grain, vegetable and manufacturing sector, respectively, can be rewritten as

$$mc_{G,t} = \frac{1}{A_{G,t}}\frac{W_t}{P_t}(T_{AM,t})^{-(1-\delta)}(T_{OGV,t})^{-\mu} \tag{2.23a}$$

$$mc_{V,t} = \frac{1}{A_{V,t}}\frac{W_t}{P_t}(T_{AM,t})^{-(1-\delta)}(T_{OGV,t})^{(1-\mu)}, \text{ and} \tag{2.23b}$$

$$mc_{M,t} = \frac{1}{A_{M,t}}\frac{W_t}{P_t}(T_{AM,t})^{\delta}. \tag{2.23c}$$

Let

$$Y_{s,t} \equiv \left(\int_0^1 Y_{s,t}(j)^{\frac{\theta-1}{\theta}} dj\right)^{\frac{\theta}{\theta-1}} \tag{2.24}$$

represent an index for aggregate sectoral output consumed for $s = OG, V$, and M, analogous to the one introduced for consumption.[10] Output demand is given by

$$Y_{s,t}(j) = \left(\frac{P_{s,t}(j)}{P_{s,t}}\right)^{-\theta} Y_{s,t}. \tag{2.25}$$

The sectoral labor supply allocation is then obtained as:

$$N_{s,t} \equiv \int_0^1 N_{s,t}(j)dj = \frac{1}{A_{s,t}}\int_0^1 Y_{s,t}(j)dj = \frac{Y_{s,t}}{A_{s,t}}\int_0^1 \left(\frac{P_{s,t}(j)}{P_{s,t}}\right)^{-\theta} dj = \frac{Y_{s,t}Z_{s,t}}{A_{s,t}} \tag{2.26}$$

$$\text{for } s = OG, V, \text{ and } M.$$

The last equality in equation (2.26) uses the sectoral output demand equation.[11] Here $Z_{s,t} = \int_0^1 \left(\frac{Ps,t(j)}{Ps,t}\right)^{-\theta} dj$ represents the price dispersion term. The price dispersion term

[10] Note that for the grain sector (G) only open market output, $Y_{OG,t}$, is consumed while the rest, $Y_{PG,t}$, is procured by the government. The total sectoral output produced in the grain sector is defined as, $Y_{G,t} = Y_{OG,t} + Y_{PG,t}$.

[11] For the grain sector, $N_{G,t} \equiv \int_0^1 N_{G,t}(j)dj = \int_0^1 \frac{Y_{G,t}(j)}{A_{G,t}}dj = \int_0^1 \frac{(Y_{PG,t}(j)+Y_{OG,t}(j))}{A_{G,t}}dj = \frac{1}{A_{G,t}}\left\{\int_0^1 Y_{PG,t}(j)dj + \int_0^1 Y_{OG,t}(j)dj\right\} = \frac{1}{A_{G,t}}\left\{Y_{PG,t} + Y_{OG,t}Z_{OG,t}\right\}.$

would be their only for the sticky price sector i.e., only the manufacturing sector and for the flexible price sectors it would be one.[12] However, equilibrium variations in the term, $\ln Z_{M,t}$, around the perfect foresight steady state are of higher order, and therefore, this term drops out for up to a first order approximation (See appendix C in Gali and Monacelli (2005)).

The Grain Sector and Price Setting

To model the institutional environment for price-setting in the grain sector, we assume that total grain produced is the sum of the amount consumed and procured. Let the government procure, $Y_{PG,t}(j)$, of each variety, j, at the market price, $P_{OG,t}(j)$. For simplicity and without loss of generality, assume that the government procures an equal amount of each variety so that $Y_{PG,t}(j) = Y_{PG,t}\ \forall j$. Therefore, $Y_{G,t}(j) = Y_{PG,t} + Y_{OG,t}(j)$. Our set-up follows Figure 2-1 described in the introduction, where higher demand for grain due to procurement, $Y_{PG,t}$, increases the market price from the market clearing level, P^*, to the higher price level, P_{OG}. Note that in our model, the higher price level at time t, $P_{OG,t}$, is the same as the minimum support price at time t (MSP_t). In other words, the government announces the amount of grain it wants to procure, $Y_{PG,t}$, based on a given MSP_t it wants to set.[13] The grain sector firms take the announced procurement amount as given and set prices, $P_{OG,t}$, optimally.

We assume that prices are flexible in the grain sector so that each firm, j, sets its price, $P_{OG,t}(j)$, to maximize profits, $\pi_{OG,t}(j)$, given by

$$\pi_{OG,t}(j) = P_{OG,t}(j)[Y_{OG,t}(j) + Y_{PG,t}] - MC_{G,t}[Y_{OG,t}(j) + Y_{PG,t}],$$

[12] This implies $Z_{OG,t} = Z_{V,t} = 1$ and $Z_{M,t} = \int_0^1 \left(\frac{P_{M,t}(j)}{P_{M,t}}\right)^{-\theta} dj$.

[13] We assume that the government in our model has complete information about the demand and supply schedules in the open market for grain. There is, however, some persistence in the amount of procurement, $Y_{PG,t}$, undertaken by the government every year. In the calibration exercise, we assume that procurement follows an AR(1) process which we estimate from the Indian data.

subject to the demand constraint

$$Y_{G,t}(j) = \left(\frac{P_{OG,t}(j)}{P_{OG,t}}\right)^{-\theta} Y_{OG,t} + Y_{PG,t}$$

in every period, for each variety j. The downward sloping demand curve for the j^{th} variety reflects the fact that farmers have some monopoly power.[14] Profit maximization results in the following price setting equation,

$$P_{OG,t}(j) = \frac{\theta}{(\theta - 1) - \frac{Y_{PG,t}}{Y_{OG,t}(j)}} MC_{G,t}. \tag{2.27}$$

Here $\frac{\theta}{\theta-1}$ is the standard price markup over marginal cost that is due to monopolistic competition. The $\frac{Y_{PG,t}}{Y_{OG,t}(j)}$ term in the denominator is the ratio of the amount procured by the government relative to the amount available in the open market. This term is new and appears due to the additional friction in the grain market resulting from the procurement of grain. In the absence of this term, equation (2.27) gives the standard equilibrium price under flexible price setting.[15] A positive shock to procurement raises the term, $\frac{Y_{PG,t}}{Y_{OG,t}(j)}$, and leads to an increase in the mark-up. Moreover, the procurement shock also acts as a time-varying mark-up shock in the grain sector.

[14] We justify this assumption by noting that many large farmers in India are also traders, and hence can be viewed as "farmer-traders."

[15] If government demand, $Y_{PG,t}$, were to be assumed similar to a household's demand function, the total demand would be,

$$\left(\frac{P_{OG,t}(i)}{P_{OG}}\right)^{-\theta} Y_{OG,t} + \left(\frac{P_{OG,t}(i)}{P_{OG}}\right)^{-\theta} Y_{PG,t}.$$

Procurement would still impact optimal prices, $P_{OG,t}(i)$, but through the marginal cost channel and not the mark-up channel. The present model however assumes that the government does not solve for the optimal demand bundle for the procured good. We assume this for two reasons. (1) The government's demand for procurement as an inverse function of prices, as mentioned above, is not consistent with open ended procurement in India. Typically, the government procures grain independent of the current market price of the grain. (2) The procurement system in place should reflect an inefficiency. Modelling procurement in the way we have makes the equilibrium deviate from its efficient level and makes the steady state distorted. Thus, we assume that the government's demand for the procured good is exogenous and is independent of the market price of grain, $P_{OG,t}$.

The Vegetable Sector and Price Setting

Prices are also assumed to be flexible in the vegetable sector. Each firm j can revise its price, $P_{V,t}(j)$, in every period to maximize profits,

$$\pi_{V,t}(j) = P_{V,t}(j) Y_{V,t}(j) - MC_{V,t} Y_{V,t}(j),$$

subject to the demand constraint

$$Y_{V,t}(j) = \left(\frac{P_{V,t}(j)}{P_{V,t}}\right)^{-\theta} Y_{V,t},$$

for variety j. Profit maximization results in the following price setting equation,

$$P_{V,t}(j) = \frac{\theta}{\theta - 1} MC_{V,t}. \tag{2.28}$$

Equation (2.28) shows that all firms in the vegetable sector set the same price given the same marginal cost and markup. Note that the only distortion in this sector is this price markup, which is due to monopolistic competition.

The Manufacturing Sector and Price Setting

The manufacturing sector differs from the two other sectors in terms of its price setting behavior. Prices are sticky in this sector and are set a la Calvo (1983). Firms adjust prices with probabilities $(1 - \alpha_M)$ independent of the time passed since the previous adjustment. By the law of large numbers a fraction of $(1 - \alpha_M)$ firms adjust prices while the rest of the firms do not. Price re-setting firm j sets a new price at period t to maximize the current value of all future profits,

$$\max_{P^*_{M,t}(j)} E_t \sum_{k=0}^{\infty} \alpha_M^k Q_{t,t+k} \left[P^*_{M,t}(j) - MC_{M,t+k}\right] Y_{M,t+k}(j)$$

subject to the demand constraint

$$Y_{M,t+k}(j) = \left(\frac{P^*_{M,t}(j)}{P_{M,t+k}}\right)^{-\theta} Y_{M,t+k}.$$

where $Q_{t,t+k} = \beta^k \left(\frac{\Gamma_{t+1}}{\Gamma_t}\right)^{1-\sigma} \left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} \left(\frac{P_t}{P_{t+1}}\right)$ is the stochastic discount factor for nominal payoffs. Profit maximization results in the following price setting equation,

$$P^*_{M,t}(j) = \frac{\theta}{\theta - 1} \frac{E_t \sum_{k=0}^{\infty} \alpha_M^k Q_{t,t+k} Y_{M,t+k}(j) MC_{M,t+k}}{E_t \sum_{k=0}^{\infty} \alpha_M^k Q_{t,t+k} Y_{M,t+k}(j)}. \tag{2.29}$$

The above equation shows that the manufacturing sector price is a markup over weighted current and expected future marginal costs. It is important to mention that under flexible prices, firms change their price whenever they get a chance to do so; therefore, the above optimal dynamic price setting boils down to its static counterpart similar to equation (2.28) as:

$$P^*_{M,t}(j) = \frac{\theta}{\theta - 1} MC_{M,t}. \tag{2.30}$$

Under sticky price setting, the dynamics of the manufacturing sector price index is given by:

$$P^{1-\theta}_{M,t} = \alpha_M (P_{M,t-1})^{1-\theta} + (1 - \alpha_M)(P^*_{M,t})^{1-\theta}. \tag{2.31}$$

Note that the nominal marginal cost entering equations (2.27), (2.28) and (2.29) are given by equation (2.22).

2.3 Equilibrium Dynamics

2.3.1 Market Clearing

Markets clear for each variety j in all three sectors. These can be written as: $C_{M,t}(j) = Y_{M,t}(j)$, $C_{OG,t}(j) + Y_{PG,t} = Y_{G,t}(j)$ and $C_{V,t}(j) = Y_{V,t}(j)$. Aggregating over all j, using the CES aggregator on consumption of sectoral goods as assumed in Section 2.2.1, we get

$$C_{M,t} = Y_{M,t} \tag{2.32a}$$

$$C_{V,t} = Y_{V,t} \tag{2.32b}$$

$$C_{OG,t} = Y_{OG,t} \tag{2.32c}$$

$$Y_{OG,t} + Y_{PG,t} = Y_{G,t}. \tag{2.32d}$$

The government budget constraint is

$$G_t = T_t = \frac{P_{OG,t}}{P_t} Y_{PG,t} \qquad \forall t. \tag{2.33}$$

Y_t, or aggregate output, can be written in "consumption-bundle" terms as,

$$Y_t = C_t + \frac{P_{OG,t}}{P_t} Y_{PG,t}. \tag{2.34}$$

The above equation is the aggregate goods market clearing condition and can be re-written as,

$$Y_t = C_t + (T_{OGV,t})^{\mu} (T_{AM,t})^{1-\delta} Y_{PG,t}. \tag{2.35}$$

Finally, the labor market clearing condition is given by,

$$N_t = N_{G,t} + N_{V,t} + N_{M,t}. \tag{2.36}$$

2.3.2 The Steady State

Define X (without t subscript) as the steady state value of the variable, X_t. Assuming no trend growth in productivity, the steady state value of $A_s = 1$ for $s = G, V$, and M. From equation (2.22), we have

$$MC_s = W$$

for $s = G, V$, and M. Steady state sectoral prices can be expressed as,

$$P_M = P_V = \frac{\theta}{(\theta-1)}W,$$
$$P_{OG} = \frac{\theta}{(\theta-1) - \frac{c_p}{1-c_p}}W,$$

where $c_p = \frac{Y_{PG}}{Y_G}$ is the share of grain procured by the government in the steady state. This gives the aggregate price level,

$$P = (1/\gamma)^{\delta(1-\mu)}\frac{\theta}{(\theta-1)}W,$$

where $\gamma = \frac{(\theta-1)(1-c_p)-c_p}{(\theta-1)(1-c_p)}$.[16] Therefore, the above sectoral prices can also be rearranged as,

$$P_M = P_V = \gamma^{\delta(1-\mu)}P,$$
$$P_{OG} = (1/\gamma)^{1-\delta(1-\mu)}P.$$

The steady state intra-sectoral and inter-sectoral TOT are,

$$T_{OGV} = 1/\gamma,$$
$$T_{AM} = (1/\gamma)^{1-\mu}.$$

respectively. Sectoral steady state consumption demands are:

$$C_M = (1-\delta)\gamma^{-\delta(1-\mu)}C, \quad (2.37a)$$
$$C_V = \mu\delta\gamma^{-\delta(1-\mu)}C, \quad (2.37b)$$
$$C_{OG} = (1-\mu)\delta\gamma^{-\delta(1-\mu)+1}C. \quad (2.37c)$$

[16]Since prices cannot be negative γ should be greater then zero such that $0 \leq \gamma \leq 1$. Imposing this restriction implies $0 \leq c_p \leq \frac{\theta-1}{\theta}$.

Steady state aggregate employment is derived from sectoral employment and market clearing conditions:

$$N = N_G + N_V + N_M = \gamma^{-\delta(1-\mu)} \left[1 + (\gamma - 1)(1-\mu)\delta\right] C + Y_{PG}. \tag{2.38}$$

2.3.3 The Log-Linearized Model

Given the steady state, we log-linearize the key relationships. Log-linearization of the Euler equation (2.13) and the labor supply equation (2.14) yields the following two equations:

$$\widehat{C}_t = E_t\{\widehat{C}_{t+1}\} - \frac{1}{\sigma}[(\widehat{R}_t - E_t\{\pi_{t+1}\}) + (1-\sigma)E_t\{\Delta\widehat{\Gamma}_{t+1}\}] \tag{2.39}$$

$$\widehat{W}_t - \widehat{P}_t = \psi\widehat{N}_t + \sigma\widehat{C}_t - (1-\sigma)\widehat{\Gamma}_t \tag{2.40}$$

where $\widehat{R}_t - E_t\{\pi_{t+1}\}$ is the (ex-ante) real interest rate. The sectoral real marginal costs (see equations (2.23a) - (2.23c)), expressed in terms of the aggregate real wage, sectoral productivity shocks, and terms of trade terms, are log-linearized to obtain the following expressions:

$$\widehat{mc}_{G,t} = \widehat{W}_t - \widehat{P}_t - \widehat{A}_{G,t} - (1-\delta)\widehat{T}_{AM,t} - \mu\widehat{T}_{OGV,t} \tag{2.41a}$$

$$\widehat{mc}_{V,t} = \widehat{W}_t - \widehat{P}_t - \widehat{A}_{V,t} - (1-\delta)\widehat{T}_{AM,t} + (1-\mu)\widehat{T}_{OGV,t} \tag{2.41b}$$

$$\widehat{mc}_{M,t} = \widehat{W}_t - \widehat{P}_t - \widehat{A}_{M,t} + \delta\widehat{T}_{AM,t} \tag{2.41c}$$

The sectoral employment equation (2.26) for the vegetable and manufacturing sectors are log-linearized as

$$\widehat{N}_{s,t} = \widehat{Y}_{s,t} - \widehat{A}_{s,t}, \tag{2.42}$$

for $s = V$ and M. For the grain sector, it is log-linearized as

$$\widehat{N}_{G,t} = c_p\widehat{Y}_{PG,t} + (1-c_p)\widehat{Y}_{OG,t} - \widehat{A}_{s,t},$$

where c_p is the steady state share of grain procured (Y_{PG}/Y_G).

Combining the log-linearized sectoral demand equations ((2.7) - (2.10)) and sectoral market clearing conditions, ((2.32a) - (2.32c)), sectoral output levels can be expressed in terms of aggregate consumption and terms of trade as:

$$\widehat{Y}_{M,t} = \widehat{C}_t + \delta\widehat{T}_{AM,t} \tag{2.43a}$$

$$\widehat{Y}_{OG,t} = \widehat{C}_t - \mu\widehat{T}_{OGV,t} - (1-\delta)\widehat{T}_{AM,t} \tag{2.43b}$$

$$\widehat{Y}_{V,t} = \widehat{C}_t + (1-\mu)\widehat{T}_{OGV,t} - (1-\delta)\widehat{T}_{AM,t}. \tag{2.43c}$$

The aggregate goods market clearing equilibrium, equation (2.35), is log linearized as:

$$\widehat{Y}_t = (1-\lambda_c)\,\widehat{C}_t + \lambda_c[\widehat{Y}_{PG,t} + \mu\widehat{T}_{OGV,t} + (1-\delta)\widehat{T}_{AM,t}] \tag{2.44}$$

where $\lambda_c = \gamma^{\delta(1-\mu)-1}c_p s_g$ and we define $s_g = \frac{Y_G}{Y} = \frac{\delta(1-\mu)}{1-c_p(1-\delta(1-\mu))}$ as the steady state share of grain sector output to total output. As can be seen in equation (2.44), the procurement of grain creates a wedge between aggregate output and aggregate consumption. Log-linearizing the labor market clearing condition (2.36), and then substituting sectoral employment in terms of sector specific output and productivity levels gives us:

$$\widehat{N}_t = \Theta_1\left[\widehat{C}_t - \widehat{A}_t + (1-\mu)(\gamma-1)\delta\left(\widehat{Y}_{OG,t} - \widehat{A}_{G,t}\right)\right] + \Theta_2\left(\widehat{Y}_{PG,t} - \widehat{A}_{G,t}\right) \tag{2.45}$$

$$\text{where } \widehat{C}_t = (1-\mu)\delta\widehat{C}_{OG,t} + \mu\delta\widehat{C}_{V,t} + (1-\delta)\widehat{C}_{M,t} \tag{2.46a}$$

$$\widehat{A}_t = (1-\mu)\delta\widehat{A}_{G,t} + \mu\delta\widehat{A}_{V,t} + (1-\delta)\widehat{A}_{M,t} \tag{2.46b}$$

$$\Theta_1 = \frac{\left(1 - c_p s_g \gamma^{[\delta(1-\mu)-1]}\right)\gamma^{-\delta(1-\mu)}}{\gamma^{-\delta(1-\mu)}\left[1+(1-\mu)(\gamma-1)\delta\right]\left(1 - c_p s_g \gamma^{[\delta(1-\mu)-1]}\right) + c_p s_g} \tag{2.46c}$$

$$\Theta_2 = \frac{c_p s_g}{\gamma^{-\delta(1-\mu)}\left[1+(1-\mu)(\gamma-1)\delta\right]\left(1 - c_p s_g \gamma^{[\delta(1-\mu)-1]}\right) + c_p s_g}. \tag{2.46d}$$

Log-linearizing and combining equations (2.29) and (2.31) yields the NKPC (New Keynesian Phillips Curve) in the manufacturing sector (for details, see Gali (2008), Chapter 3),

$$\pi_{M,t} = \beta E_t\{\pi_{M,t+1}\} + \lambda_M \widehat{mc}_{M,t} \tag{2.47}$$
$$\text{where } \lambda_M = \frac{(1-\alpha_M)(1-\alpha_M\beta)}{\alpha_M}.$$

Note that the above log-linearized expression of the price setting equation in the manufacturing sector is independent of θ, the elasticity of substitution between the varieties within this sector. Similarly, the log linearized expression of the pricing equation (2.48) in the vegetable sector as shown below is independent of θ. However, a similar log-linearized price setting equation (2.49) to the grain sector is not independent of θ as shown below

$$\widehat{mc}_{V,t} = 0, \tag{2.48}$$
$$\widehat{mc}_{G,t} = \left(\frac{c_p}{(\theta-1)(1-c_p)-c_p}\right)\left(\widehat{Y}_{OG,t} - \widehat{Y}_{PG,t}\right) \tag{2.49}$$

It should be noted that assuming different values of θ for different sectors will not change the dynamics as only θ for the grain sector, θ_G, will show up in the log-linearized (up to first order) system of equations of the model. This would be equivalent to assuming the same value of θ for different sectors.

Shock processes

The structural shock processes in log-linearized form are assumed to follow AR(1) processes,

$$\Delta \ln A_{G,t} = \rho_{A_G}\ \Delta \ln A_{G,t-1} + \epsilon_{A_G,t}\ ,\ \epsilon_{A_G,t} \sim i.i.d.\ (0, \sigma_{A_G}) \tag{2.50a}$$

$$\Delta \ln A_{V,t} = \rho_{A_V}\ \Delta \ln A_{V,t-1} + \epsilon_{A_V,t}\ ,\ \epsilon_{A_V,t} \sim i.i.d.\ (0, \sigma_{A_V}) \tag{2.50b}$$

$$\Delta \ln A_{M,t} = \rho_{A_M}\ \Delta \ln A_{M,t-1} + \epsilon_{A_M,t}\ ,\ \epsilon_{A_M,t} \sim i.i.d.\ (0, \sigma_{A_M}) \tag{2.50c}$$

$$\ln Y_{PG,t} - \ln Y_{PG} = \rho_{Y_{PG}} (\ln Y_{PG,t-1} - \ln Y_{PG}) + \epsilon_{Y_{PG},t}\ ,\ \epsilon_{Y_{PG},t} \sim i.i.d.\ (0, \sigma_{Y_{PG}}) \tag{2.50d}$$

The flexible-price equilibrium and the natural level

Under flexible prices, the pricing decisions of firms are synchronized. We have sticky prices only in the manufacturing sector. Under flexible prices, price setting boils down to a static decision and each firm sets price by equation (2.30): $P^*_{M,t} = \frac{\theta}{\theta-1} MC_{M,t}$, which implies a constant real marginal cost. This in turn implies that the real marginal cost log-deviation is zero. We already have flexible prices in both the agricultural sub-sectors. However, given procurement in the grain sector, the real marginal cost log-deviation is non-zero. This is given by the log-linearization of equation (2.27) ,

$$\widehat{mc}^n_{G,t} = \Phi(\widehat{Y}^n_{OG,t} - \widehat{Y}_{PG,t}). \tag{2.51}$$

where $\Phi = \frac{c_p}{(\theta-1)(1-c_p)-c_p}$. The superscript, n, is used to denote the natural level of a variable. Here, it is important to stress that the grain procured by the government will be the same under any pricing assumption, so that $\widehat{Y}_{PG,t} = \widehat{Y}^n_{PG,t}$. In the case of the manufacturing and vegetable sectors, $\widehat{mc}^n_{V,t} = \widehat{mc}^n_{M,t} = 0$. Using these conditions for the real marginal cost log-deviation, equations $(2.41a - 2.41c)$ can be expressed as

$$\widehat{T}^n_{OGV,t} = -\Phi(\widehat{Y}^n_{OG,t} - \widehat{Y}_{PG,t}) + \widehat{A}_{V,t} - \widehat{A}_{G,t} \tag{2.52}$$

$$\widehat{T}^n_{AM,t} = -\Phi\,(1-\mu)\,(\widehat{Y}^n_{OG,t} - \widehat{Y}_{PG,t}) + \widehat{A}_{M,t} - (1-\mu)\,\widehat{A}_{G,t} - \mu\widehat{A}_{V,t} \tag{2.53}$$

The Euler equation can be rewritten in the flexible price equilibrium as,

$$\widehat{C}^n_t = E_t\{\widehat{C}^n_{t+1}\} - \frac{1}{\sigma}[(\widehat{R}^n_t - E_t\{\pi^n_{t+1}\}) + (1-\sigma)E_t\{\Delta\widehat{\Gamma}_{t+1}\}], \tag{2.54}$$

where $\widehat{R}^n_t$ and π^n_t denote the nominal interest rate and inflation rate under flexible price setting. At a flexible price equilibrium the real wage equation can be derived as

$$\widehat{w}^n_t = \widehat{A}_t + \Phi\,(1-\mu)\,\delta(\widehat{Y}^n_{OG,t} - \widehat{Y}_{PG,t}), \tag{2.55}$$

where $w = \frac{W}{P}$. Using (2.55), (2.40), and (2.45), at a flexible price equilibrium, the natural level of consumption, $\widehat{C}^n_t$, can be expressed as

$$\begin{aligned}\widehat{C}^n_t = {} & \frac{(\psi\Theta_1 + 1)}{(\psi\Theta_1 + \sigma)}\widehat{A}_t - \frac{(\Phi\,(1-\mu)\,\delta + \psi\Theta_2)}{(\psi\Theta_1 + \sigma)}\widehat{Y}_{PG,t} + \frac{(\Phi\,(1-\mu)\,\delta - \psi\Theta_1\,(\gamma-1)\,(1-\mu)\,\delta)}{(\psi\Theta_1 + \sigma)}\widehat{Y}^n_{OG,t} \\ & + \frac{(1-\sigma)}{(\psi\Theta_1 + \sigma)}\widehat{\Gamma}_t + \frac{(\psi\Theta_1\,(\gamma-1)\,(1-\mu)\,\delta + \psi\Theta_2)}{(\psi\Theta_1 + \sigma)}\widehat{A}_{G,t}.\end{aligned} \tag{2.56}$$

Now using the demand equations in a flexible price equilibrium, the natural levels of output for the grain, vegetable and manufacturing sectors can be expressed, respectively, as

$$\widehat{Y}^n_{OG,t} = \widehat{C}^n_t - \mu\widehat{T}^n_{OGV,t} - (1-\delta)\,\widehat{T}^n_{AM,t}, \tag{2.57a}$$

$$\widehat{Y}^n_{V,t} = \widehat{C}^n_t + (1-\mu)\widehat{T}^n_{OGV,t} - (1-\delta)\,\widehat{T}^n_{AM,t}, \tag{2.57b}$$

$$\widehat{Y}^n_{M,t} = \widehat{C}^n_t + \delta\widehat{T}^n_{AM,t}, \tag{2.57c}$$

where $\widehat{C}_t^n$ is given by equation (2.56). The aggregate natural level of output, $\widehat{Y}_t^n$, can be expressed as,

$$\widehat{Y}_t^n = (1-\lambda_c)\,\widehat{C}_t^n + \lambda_c[\widehat{Y}_{PG,t} + \mu\widehat{T}_{OGV,t}^n + (1-\delta)\widehat{T}_{AM,t}^n]. \tag{2.58}$$

Equations (2.51) - (2.58) show how the presence of procurement affects the natural level of variables in the model. Procurement affects these equations as an additive shock since we assume later that procurement follows an AR(1) process. Procurement also affects these equations through the parameter, c_p, which enters into the structural coefficients in front of the variables.

The Sticky price equilibrium

We define a variable, $\widetilde{X}_t = \widehat{X}_t - \widehat{X}_t^n$, to be the deviation from the natural level. Using equations (2.40), (2.41c) and (2.45) we can write $\widetilde{mc}_{M,t}$ in terms of the manufacturing sector output gap, $(\widehat{Y}_{M,t} - \widehat{Y}_{M,t}^n)$:

$$\widetilde{mc}_{M,t} = \widehat{mc}_{M,t} = (\psi\Theta_1 + \sigma)\,\widetilde{Y}_{M,t} - \delta\,(\psi\Theta_1 + \sigma - 1)\,\widetilde{T}_{AM,t} \tag{2.59}$$

Hence, the NKPC in equation (2.47) for the manufacturing sector becomes

$$\pi_{M,t} = \beta E_t\{\pi_{M,t+1}\} + \lambda_M\,(\psi\Theta_1 + \sigma)\,\widetilde{Y}_{M,t} - \lambda_M\delta\,(\psi\Theta_1 + \sigma - 1)\,\widetilde{T}_{AM,t}. \quad \text{(2.60a)}$$

$$= \beta E_t\{\pi_{M,t+1}\} + \lambda_M\,(\psi\Theta_1 + \sigma)\,\widetilde{C}_t + \lambda_M\delta\widetilde{T}_{AM,t}. \quad \text{(2.60b)}$$

Equation (2.60b) shows that inflation in the manufacturing sector sector gets affected by terms of trade changes and aggregate consumption demand. This happens because the demand for the manufacturing sector good depends on the terms of trade and the aggregate consumption demand conditions, as shown in equation (2.43a). Also note that the presence of procurement reduces the effect of aggregate consumption on inflation as procurement lowers the consumed part of aggregate output. Since prices are flexible in the vegetable and manufacturing sectors, no such individual NKPC exists in either sector. However, because of procurement there is a static "Phillips curve" type equation in the grain sector as can be seen from equation (2.49). Combining equations (2.44) and (2.58), we obtain

$$\widetilde{Y}_t = (1-\lambda_c)\,\widetilde{C}_t + \lambda_c(1-\delta)\widetilde{T}_{AM,t}. \tag{2.61}$$

For the aggregate analysis, it is convenient to express the NKPC in terms of CPI inflation. Equations $(2.60a)$ and (2.61) with equations $(2.43a - 2.43c)$, (2.56) and, $\pi_t - \pi_{M,t} = \delta\Delta\widehat{T}_{AM,t}$, can be rearranged to get the aggregate NKPC for the economy:

$$\begin{aligned}\pi_t \;&=\; \beta E_t\{\pi_{t+1}\} + \lambda_M \frac{(\psi\Theta_1+\sigma)}{(1-\lambda_c)}\widetilde{Y}_t + \lambda_M\left(\delta - \frac{\lambda_c\,(\psi\Theta_1+\sigma)\,(1-\delta)}{1-\lambda_c}\right)\widetilde{T}_{AM,t} \\ &\quad +\delta\Delta\widehat{T}_{AM,t} - \beta\delta E_t\{\Delta\widehat{T}_{AM,t+1}\}.\end{aligned} \tag{2.62}$$

The right hand side of the equation (2.62) can be consolidated and written in terms of aggregate consumption and terms of trade terms as,

$$\begin{aligned}\pi_t \;&=\; \beta E_t\{\pi_{t+1}\} + \lambda_M\,(\psi\Theta_1+\sigma)\,\widetilde{C}_t + \lambda_M\delta\widetilde{T}_{AM,t} \\ &\quad +\delta\Delta\widehat{T}_{AM,t} - \beta\delta E_t\{\Delta\widehat{T}_{AM,t+1}\}.\end{aligned} \tag{2.63}$$

Similar to equation $(2.60b)$ aggregate inflation in (2.63) depends on the terms of trade and aggregate consumption demand. This equation is very similar to the aggregate NKPC derived in Aoki (2001), except that the presence of procurement affects the impact that aggregate consumption has on inflation as procurement lowers the consumed part of aggregate output (as in (2.44)). Also, the terms of trade terms in (2.62) shift the Phillips curve. These terms capture the effect of terms of trade shocks on aggregate inflation.

Similarly, we derive the aggregate DIS equation by combining equations (2.39), (2.54) and (2.61):

$$\widetilde{Y}_t = E_t\{\widetilde{Y}_{t+1}\} - \frac{(1-\lambda_c)}{\sigma}[(\widehat{R}_t - E_t\{\pi_{t+1}\}) - \widehat{r}_t^n] - \lambda_c(1-\delta)E_t\left\{\Delta\widetilde{T}_{AM,t+1}\right\}, \tag{2.64}$$

where, $\widehat{r}_t^n = \sigma E_t\{\Delta\widehat{C}_{t+1}^n\} - (1-\sigma)E_t\{\Delta\widehat{\Gamma}_{t+1}\}$, is the natural rate of interest.

The NKPC and DIS equations at the aggregate level along with a monetary policy rule constitute the basis of our analysis for output and inflation dynamics.

Monetary Policy Rule

Since monetary policy follows a simple Taylor's rule with the nominal interest rate as a function of aggregate inflation and the economy wide output gap, monetary policy gets affected with procurement policy. To capture this, we use a simple generalization of Taylor (1993):

$$R_t = (R_{t-1})^{\phi_r} (\pi_t)^{\phi_\pi} \left(\frac{Y_t}{Y_t^n}\right)^{\phi_y}$$

The log-linearized version of the Taylor-rule shows that:

$$\begin{aligned} \widehat{R}_t &= \phi_r \widehat{R}_{t-1} + \phi_\pi \pi_t + \phi_y(\widehat{Y}_t - \widehat{Y}_t^n) \\ &= \phi_r \widehat{R}_{t-1} + \phi_\pi \pi_t + \phi_y \widetilde{Y}_t \end{aligned} \tag{2.65}$$

i.e., the nominal interest rate, $\widehat{R}_t$, depends on its lagged value, aggregate inflation's deviation from its target, π_t, and the aggregate output gap, $\widetilde{Y}_t$.[17] This closes the model.

2.3.4 Difference between NKPC and the DIS with and without procurement

Without a procurement distortion ($c_p = 0$, $\lambda_c = 0$), the aggregate NKPC and DIS equations in (2.62) and (2.64) respectively are:

$$\pi_t = \beta E_t\{\pi_{t+1}\} + \lambda_M (\psi + \sigma) \widetilde{Y}_t + \lambda_M \delta \widetilde{T}_{AM,t} + \delta \Delta \widehat{T}_{AM,t} - \beta\delta E_t\{\Delta \widehat{T}_{AM,t+1}\} \tag{2.66}$$

$$\widetilde{Y}_t = E_t\{\widetilde{Y}_{t+1}\} - \frac{1}{\sigma}[(\widehat{R}_t - E_t\{\pi_{t+1}\}) - \widehat{r}_t^n]. \tag{2.67}$$

[17] We assume that the inflation target is zero.

Equation (2.66) above is a standard NKPC for a multi-sector set-up.[18] As in Aoki (2001) changes in the terms of trade leads to shifts in the NKPC. In contrast, the DIS equation in a multi-sector set-up is not affected by the terms of trade as seen in equation (2.67). On the other hand, the presence of procurement, as can be seen from equation (2.64) adds a terms of trade term which shifts the DIS equation too.[19] The terms of trade also shifts the NKPC. Since a procurement shock shifts both the NKPC and the DIS curves, it acts as a supply shock as well as a demand shock respectively. Note that, when there is no procurement the NKPC still retains some terms of trade expressions because of the multi-sector set-up.

Moreover, we can show that when, $0 \leq \lambda_c \leq 1$, the slope of the DIS curve and the NKPC increases monotonically with higher values of the steady state procurement parameter, c_p.[20]

Suppose $\lambda_c > 0$. An increase in the slope of the NKPC means that for a given level of the output gap, $\widetilde{Y}_t$, aggregate inflation, π_t, is higher. Moreover, in the DIS equation, (2.64), the response of aggregate output to a change in the real interest depends on the value of, σ, and, λ_c. For positive values of c_p, this responsiveness of the output gap to changes in the real interest rate becomes less, making the DIS curve steeper.

[18]See Aoki (2001), p. 64-66.

[19]Note that in equation (2.64) the term $E_t\{\Delta T_{AM,t+1}\}$ exists only in the presence of procurement i.e. $\lambda_c > 0$ when $c_p > 0$ and $\lambda_c = 0$ when $c_p = 0$.

[20]We require the sufficient condition, $0 \leq \lambda_c \leq 1$, to show the following results. We first note that, λ_c, is given by the steady state ratio, $C/Y = 1 - \lambda_c$, which implies, $0 \leq \lambda_c \leq 1$. We therefore restrict the value of c_p such that $0 \leq \lambda_c \leq 1$. We can show

$$\frac{d(\frac{(\psi\Theta_1+\sigma)}{(1-\lambda_c)})}{dc_p} = \frac{\left(\psi\frac{d\Theta_1}{dc_p}\right)(1-\lambda_c) + \left(\frac{d\lambda_c}{dc_p}\right)(\psi\Theta_1+\sigma)}{(1-\lambda_c)^2} > 0 \;\forall\; c_p$$

where $\frac{(\psi\Theta_1+\sigma)}{(1-\lambda_c)}$ is the slope of the NKPC which increases in c_p. Similarly, it can be shown that

$$\frac{d(\frac{\sigma}{1-\lambda_c})}{dc_p} = \frac{\left(\frac{d\lambda_c}{dc_p}\right)\sigma}{(1-\lambda_c)^2} > 0$$

since $\frac{d\lambda_c}{dc_p} > 0, \forall\; c_p$, where, once again, we have imposed $0 \leq \lambda_c \leq 1$. The slope of the DIS curve is also increasing in c_p.

This implies that to achieve a given output gap, a greater change in the real interest rate is required. The slope changes because procurement creates a wedge between the output produced and the output consumed. The changes in the real rate of interest however affects only output consumed which is a constant proportion of total output. Hence, procurement weakens monetary policy transmission since monetary transmission only applies to consumed output. Moreover, a positive steady state procurement level distorts the steady state level of all variables which makes aggregate inflation higher and the economy-wide output gap also higher.

2.4 Calibration

In this section, we calibrate the model to the Indian data.[21] Our goal is to understand the quantitative implications of a positive procurement shock to the economy and compare it with a negative productivity shock. We consider these two cases because they typify the kind of shocks experienced by the Indian agriculture sector. Hence, we give a single period positive procurement shock and analyze its effect on inflation, the output-gap and sectoral labor reallocation. We then contrast this with a single period negative productivity shock. We use the impulse response functions to assess implications for monetary policy set by the Reserve Bank of India, or more generally, emerging market central banks who face terms of trade shocks. In particular, we will see how a single period procurement and productivity shock affects the deviations of various variables from their steady state values.[22]

[21]We calibrate our model using Dynare Version 4.4.2.

[22]The results are robust to the calibrated values of the parameters in the model. To verify this we did the sensitivity analysis around $\pm 10\%$ range of the value of the calibrated parameters and the results remain qualitatively the same.

2.4.1 Description of parameters

It is well known that the values of several structural parameters are unknown in developing and emerging market economies. Therefore, while we use some parameter estimates from the literature, we also estimate some parameters from the data. We set the discount factor for India at $\beta = .9823$ as calibrated in Levine (2012). We choose the value of the inverse of the Frisch elasticity of substitution, $\psi = 3$ (Anand and Prasad (2010)). We fix the value of the inter-temporal elasticity of substitution, $\sigma = 1.99$, as estimated in Levine (2012).[23] We calculate the expenditure share on agriculture sector goods and vegetable sector goods to be, $\delta = 0.52$, $\mu = 0.44$, using household expenditure data, NSS (National Sample Survey) 68^{th} Round $(2011 - 12)$.[24] We fix the elasticity of substitution between varieties of the same sector goods, $\theta = 7.02$, as estimated by Levine (2012). We set the measure of stickiness for the manufacturing sector, $\alpha_M = 0.75$, as estimated in Levine (2012) for the formal sector in India. We choose the value of AR(1) coefficients in equation $(2.50a - 2.50c)$ and standard error of these regressions following Anand and Prasad (2010).[25] Thus, for productivity shocks in the agriculture sector, the AR(1) coefficient for

[23]Levine (2012) estimate a closed economy DSGE model for India using Bayesian estimation. They use data for real GDP, real investment, the GDP deflator, and the nominal interest rate for India from 1996:1 (i.e. first quarter)-2008:4 (i.e. last quarter). We use the estimated values for the 2-sector NK model from their paper.

[24]The household expenditure data of the NSS (National Sample Survey) 68^{th} Round $(2011-12)$, breaks down item-wise average monthly expenditure incurred by rural and urban households (i.e., expenditures on cereals and cereal substitutes, pulses, vegetables, fruits, services, etc.). According to this round, the food expenditure share in total consumption expenditure is approximately 52.9% in rural India and 42.6% in urban India. For total household consumption expenditure, we exclude services as an item group since we don't consider services in our model. Net of services, we then sum the monthly per capita expenditure of the following items: cereals and cereal substitutes, pulses and their products, vegetables, fruits, fuel and light, clothing and footwear, and durable goods. These items proxy for consumed items in the agriculture and the manufacturing sector. The items relevant to the agriculture sector are: cereals and cereal substitutes, pulses and their products, vegetables, fruits. We sum the monthly per-capita expenditures for these items, and calculate their share in total consumption for rural and urban households. Finally, we use the Census of India (2011) population weights of rural and urban households to obtain the parameter, δ, as a weighted average of rural and urban agriculture consumption expenditure. Similarly, we calculate the expenditure share on vegetables as a percentage to total expenditure on agriculture sector goods, μ.

[25]Anand and Prasad (2010) assumes persistence for a food sector shock in an AR(1) process to be 0.25. Assuming any productivity shock to the grain sector will be same for the vegetable sector, we have set the AR(1) coefficient same for both.

grain and vegetable sector is calibrated to be, $\rho_{A_G} = \rho_{A_V} = 0.25$ and for the manufacturing sector, $\rho_{A_M} = 0.95$. The standard error of regression for the grain and the vegetable sector is given by, $\sigma_{A_G} = \sigma_{A_V} = 0.03$, and for the manufacturing sector, $\sigma_{A_M} = 0.02$. We estimate an AR(1) process on procurement in the grain sector as described in equation (2.50d) using the procurement data published by the Ministry of Consumer Affairs (MCA), India from 1992-2012.[26] We fix the interest rate smoothening parameter, $\phi_R = 0$, initially. We put standard weights on inflation, $\phi_\pi = 1.5$, and the output gap, $\phi_y = 0.5$, in the Taylor Rule (Taylor (1993)). We calculate the steady state value of c_p to be 0.08 using the annual grain production data from the RBI Indian database and procurement data from the Ministry of Consumer Affairs from 1992-2012.[27] We get this steady state by taking the average of the ratio of the net procured good to total production of wheat and rice. Finally, we ignore the role of preference induced demand shocks in the model, i.e., $\Gamma_t = 1 \ \forall \ t$. Table 2.2 summarizes the structural parameters used in the calibration exercise in our model and their values.

2.4.2 Transmission of a single period positive procurement shock in the grain sector

Figures 2-2 - 2-5 plot the impulse response functions of a single period positive procurement shock, $\widehat{Y}_{PG,t}$.

[INSERT FIGURE 2-2 - FIGURE 2-5]

On impact a positive procurement shock increases the markup over marginal cost, $\widehat{MC}_{G,t}$, as shown in equation (2.27). This increases the open grain market goods price, leading to inflation in this sector, $\pi_{OG,t}$, (see Figure 2-3 (row 1, column 1)).

[26]Department of Food & Public Distribution, see http://dfpd.nic.in/. Only Wheat and Rice data is considered. We use the net procured good series. To get this we subtract the amount distributed through the public distribution system (PDS) from the procured amount every year. First we take log of this net procured good series and then demean it to get the $\widehat{Y}_{PG,t}$ series. On this series we estimate an AR(1) process to get $\rho_{Y_{PG}} = 0.4$ and a standard error $\sigma_{Y_{PG}} = 0.66$.

[27]For production data, see https://www.rbi.org.in/Scripts/PublicationsView.aspx?id=15807

Parameter	Notation	Value	Source
Discount factor	β	.9823	Levine (2012)
Inverse of Frisch elasticity of labor supply	ψ	3	Anand and Prasad (2010)
Inverse of inter-temporal elasticity of substitution	σ	1.99	Levine (2012)
Share of total consumption expenditure allocated to agriculture sector goods	δ	0.52	Calculated by Authors
Share of total food consumption expenditure allocated to vegetable sector goods	μ	0.44	Calculated by Authors
Elasticity of substitution between the varieties of same sector goods	θ	7.02	Levine (2012)
Measure of stickiness (M)	α_M	0.75	Levine (2012)
AR(1) coefficients			
Productivity shock in grain sector (G)	ρ_{A_G}	0.25	Anand and Prasad (2010)
Productivity shock in vegetable sector (V)	ρ_{A_V}	0.25	Anand and Prasad (2010)
Productivity shock in manufacturing sector (M)	ρ_{A_M}	0.95	Anand and Prasad (2010)
Procurement in grain sector (PG)	$\rho_{Y_{PG}}$	0.4	Estimated by Authors
Standard error of AR(1) process			
Grain Sector (G)	σ_{A_G}	0.03	Anand and Prasad (2010)
Vegetable Sector (V)	σ_{A_V}	0.03	Anand and Prasad (2010)
Manufacturing Sector (M)	σ_{A_M}	0.02	Anand and Prasad (2010)
Procurement in grain sector (PG)	$\sigma_{Y_{PG}}$	0.66	Estimated by Authors
Taylor rule Parameters			
Interest rate smoothing	ϕ_R	0	
Weight on inflation gap	ϕ_π	1.5	Taylor (1993)
Weight on output gap	ϕ_y	0.5	Taylor (1993)

Table 2.2: Summary of parameter values

At the same time this increase in the markup reduces real marginal costs in the grain sector (see equation (2.51)), making firms produce more grain, $\widehat{Y}_{G,t}$, which increases the demand for labor, $\widehat{N}_{G,t}$, (see Figure 2-4 (row 2, column 2) and 2-5 (row 1, column 1)).[28] The nominal wage rises in this sector because of higher labor demand and labor gets pulled out from the other two sectors as shown in Figure 2-4 (row 3, column 1 and 2). Labor supply in the manufacturing sector, $\widehat{N}_{M,t}$, and in the vegetable sector, $\widehat{N}_{V,t}$, keep on falling till the time nominal wages equalize in all the sectors.[29] The firms in these two sectors revise their prices upward due to higher nominal wages in their sectors leading to positive inflation in, $\pi_{M,t}$ and $\pi_{V,t}$, (see Figure 2-3 ((row 1, column 2) and (row 2, column 1))). This is the mechanism through which the inflationary impact of a positive procurement shock gets transmitted to other sectors and leads to aggregate inflation, π_t, (see Figure 2-3 (row 2, column 2)).

Since a positive procurement shock acts as a negative cost push shock (because of higher nominal wages), output in the manufacturing sector, $\widehat{Y}_{M,t}$, and the vegetable sector, $\widehat{Y}_{V,t}$, falls on impact. As, the manufacturing sector is a sticky price sector and thus only a fraction of firms revise their prices, this creates a positive output gap, $\widetilde{Y}_{M,t}$, in this

[28] Note although the output of the grain sector, $\widehat{Y}_{G,t}$, increases, this increase is less than the procured quantity leading to a fall in open market grain output, $\widehat{Y}_{OG,t}$ (see Figure 2-5 (row 1, column 1 and 2)).

[29] Labour moves across sectors on impact because it is assumed that the labour market is completely flexible. In the presence of labour adjustment costs, labour mobility would be reduced and we would not observe such sharp labour/ output movements across sectors. Although we could not find direct empirical evidence on the labour reallocation effect of procurement, there is some suggestive evidence in the literature on reallocation of land resources to certain crops in the presence of procurement. This land reallocation is visible in the form of changes in cropping patterns in states in India where minimum supports prices and procurement policy is effective (see Deshpande (2003), Gupta (1980), DMEO (2016)).For instance, Deshpande (2003) observes that farmers in states like Punjab are lured by the increase in prices and effective Minimum Support Prices particularly of wheat and paddy, at which their produce was procured, and show a clear evidence of a shift towards production of rice and wheat in this state. In fact, the farmers also face a problem of glut in wheat and paddy in the market. Similar patterns have also been observed in certain districts of the state of Andhra Pradesh, as discussed in DMEO (2016). These state level observations clearly show that price support and procurement by the government does lead to a re-allocation of resources, in this case land, towards crops which are supported. More production of crops which are supported would suggest more labor is hired to produce them. Thus, the model prediction of resources moving towards the sectors which are supported captures the essence of this argument.

sector. More specifically, a positive output gap in the manufacturing sector, $\widehat{Y}_{M,t} - \widehat{Y}^n_{M,t}$, results because a positive procurement shock in the grain sector leads to a reduction in manufacturing sector output. Due to price stickiness in the manufacturing sector, actual output, $\widehat{Y}_{M,t}$, falls by less value than its natural level, $\widehat{Y}^n_{M,t}$, and thus the term, $\widehat{Y}_{M,t} - \widehat{Y}^n_{M,t}$, becomes positive on impact. At the same time the economy wide output gap, $\widetilde{Y}_t$, also rises as shown in Figure 2-5 (row 3, column 3). Monetary policy responds to this increase in inflation and the positive output gap by an increase in the nominal interest rate, $\widehat{R}_t$ (see equation (2.65)) given the Taylor rule parameters in Table 2.2. This increase in the nominal interest rate, adjusted for a one period future expected inflation increases the real interest rate, $\widehat{r}_t$, as shown in Figure 2-4 (row 1, column 2).[30] From the Euler equation (2.39), a rise in the real interest rate induces current consumption, $\widehat{C}_t$, to fall due to the inter-temporal substitution effect. From the demand function (equations $(2.43a - 2.43c)$), the sectoral demand for goods will depend upon the income effect from falling consumption, $\widehat{C}_t$, and the inter-good substitution effect due to the changing terms of trade, $\widehat{T}_{AM,t}$ and $\widehat{T}_{OGV,t}$. As can be seen from Figure 2-4 ((row 1, column 2 and 3) and (row 2, column 2)), the income effect dominates and the quantity demanded falls for all three sectors in the first period using the calibrated parameters from Table 2.2.[31] Over time the economy goes back to the steady state.

[30]See Taylor (1999) for a discussion of the advantages of a variety of "simple rules" over optimal interest rate rules of the following form,

$$\widehat{R}_t = \widehat{r}^n_t + \phi_\pi \pi_t + \phi_y \widetilde{Y}_t,$$

where $\widehat{r}^n_t$ is the time varying natural rate of interest. We consider a "simple rule" as these rules are easy to implement by central banks. We also conducted a sensitivity analysis with the above optimal interest rate rule and our simple rule in equation (2.65). We find that the impact of a procurement shock on the nominal interest rate is very similar (0.0143 under equation (2.65) versus 0.0147 with the optimal interest rate rule).

[31]We have done a sensitivity analysis for different values of δ (i) arbitrarily setting it to be low ($\delta = .05$) and high ($\delta = .70$), and (ii) setting δ equal to the food expenditure share in total consumption in other EMEs (e.g., China (0.38), Brazil (0.24), Russia (0.30)) using data from the BRICS (2015). We have looked at the impulse responses of the variables for a one period positive procurement shock. A higher/lower value of δ does increase/decrease the value of inflation on impact, as would be expected. However, inflation increases at a decreasing rate as δ increases.

2.4.3 Transmission of a single period negative productivity shock in the grain sector

Figures 2-6 - 2-8 plot the impulse response functions of a single period negative productivity shock, $\widehat{A}_{G,t}$.[32]

[INSERT FIGURE 2-6 - FIGURE 2-8]

On impact, a negative productivity shock reduces grain output, $\widehat{Y}_{G,t}$, and increases the nominal marginal cost, $\widehat{MC}_{G,t}$, leading to positive inflation in the grain sector, $\pi_{OG,t}$, as shown in Figure 2-6 (row 2, column 1). A rise in the prices of the grain sector good induces consumers to shift their demand to other sector goods, $\widehat{Y}_{M,t}$ and $\widehat{Y}_{V,t}$, (see Figure 2-8 (row 1, column 1 and 3)). Foreseeing this rise in demand, the manufacturing and vegetable sector firms increase their output by employing more labor, $\widehat{N}_{M,t}$ and $\widehat{N}_{V,t}$. This increase in the labor demand increases the nominal wages across all sectors. The manufacturing and vegetable sector firms revise their prices upward leading to positive inflation in these two sectors, $\pi_{M,t}$ and $\pi_{V,t}$, as shown in Figure 2-6 ((row 1, column 2) and (row 2, column 1)). This is the mechanism through which the inflationary impact of a negative productivity shock gets transmitted to other sectors and leads to aggregate inflation, π_t, (see Figure 2-6 (row 2, column 2)).

Since a negative productivity shock acts as a positive demand shock to the other two sectors (for their goods), the output in these two sectors, $\widehat{Y}_{M,t}$ and $\widehat{Y}_{V,t}$, rises on impact. As, the manufacturing sector is a sticky price sector and thus only a fraction of firms revise their prices and this creates a negative output gap, $\widetilde{Y}_{M,t}$, in this sector on impact. More specifically, negative output gap in the manufacturing sector, $\widehat{Y}_{M,t} - \widehat{Y}^n_{M,t}$, results because a negative productivity shock in the grain sector leads to a rise in the demand for manufacturing sector goods. Due to price stickiness in the manufacturing sector, actual output, $\widehat{Y}_{M,t}$, rises by less value than its natural level, $\widehat{Y}^n_{M,t}$, and thus the term, $\widehat{Y}_{M,t} - \widehat{Y}^n_{M,t}$,

[32] For this exercise we assume no procurement distortion i.e. $\widehat{Y}_{PG,t}$ and c_p is zero.

becomes negative on impact. At the same time the economy wide output gap, $\widetilde{Y}_t$, also falls slightly as shown in Figure 2-8 (row 3, column 1). Monetary policy responds to this increase in inflation and slightly negative output gap by an increase in the nominal interest rate, $\widehat{R}_t$ (see equation (2.65)) given the Taylor rule parameters in Table 2.2. This increase in the nominal interest rate, adjusted for a one period future expected inflation increases the real interest rate, $\widehat{r}_t$, as shown in Figure 2-7 (row 1, column 2). From the Euler equation (2.39), a rise in the real interest rate induces current consumption, $\widehat{C}_t$, to fall due to the inter-temporal substitution effect. From the demand function (equations $(2.43a - 2.43c)$), the sectoral demand for goods will depend upon the income effect from falling consumption, $\widehat{C}_t$, and the inter-good substitution effect due to the changing terms of trade, $\widehat{T}_{AM,t}$ and $\widehat{T}_{OGV,t}$. As can be seen from Figure 2-8 (row1, column 1 and 3), the substitution effect dominates and the quantity demanded rises for manufacturing and vegetable sector goods in the first period using the calibrated parameters from Table 2.2. Over time the economy goes back to the steady state.

2.5 Implications for the Reserve Bank of India

The above calibration exercise suggests that both a positive procurement shock and a negative productivity shock leads to positive aggregate inflation and a qualitatively similar response from the central bank. As discussed above, both differ strikingly from each other in how the shock gets transmitted to the aggregate economy. Figure 2-9 plots the monetary policy response for a range of values of $c_p \in [0, 0.6]$, for a common single period procurement shock , $\widehat{Y}_{PG,t}$, on impact.

[INSERT FIGURE 2-9]

Figure 2-9 shows a non-linear, increasing and monotonic relation between $\widehat{R}_t$ and c_p. From equation (2.65), the nominal interest rate $\widehat{R}_t$ depends on aggregate inflation, π_t, and the aggregate output gap, $\widetilde{Y}_t$. A higher interest rate response of the monetary authority on impact for higher values of c_p is thus possible if and only if higher values of c_p lead to higher aggregate inflation or a higher aggregate output gap or both. To understand this it is important to see how c_p changes the aggregate NKPC and DIS curves. From equation (2.62), and under the sufficient condition, $0 < \lambda c \leq 1$, a higher value of c_p makes the aggregate NKPC steeper which means a given output gap is now associated with higher inflation. Moreover, according to the DIS equation, (2.64) , the response of the real economy to changes in the real interest rate, $\widehat{r}_t$, decreases with higher values of c_p, thus requiring a stronger monetary response for a given output gap. Hence the monetary policy response for a procurement shock should depend on the steady state value of c_p. This figure implies that central banks in EMDEs like the Reserve Bank of India should respond to changes in the terms of trade over time in a systematic way as outlined in our model, especially since the importance of food inflation in monetary policy setting over the last several years has become increasingly important (Reserve Bank of India (2015)).

2.6 Conclusion

Central banks in EMDEs such as India often grapple with understanding the inflationary impact of a shock from the agriculture sector because the precise relationship between aggregate inflation and the terms of trade may be unknown. To address this, we develop a three-sector (grain, vegetable, and manufacturing) closed economy NK-DSGE model for the Indian economy to understand how one major distortion - the procurement of grain by the government – affects overall inflationary pressures in the economy via changes in the sectoral terms of trade. Our main contribution is to identify the mechanism through which changes in the terms of trade – because of changes in procurement – leads to aggregate inflation, changes in sectoral output gaps, sectoral resource allocation, and the economy wide output gap. We then calibrate the model to India to discuss the role of monetary policy in such a set-up. We show that a positive procurement shock to grain leads to higher inflation, a change in the sectoral terms of trade, and a positive output gap because of a change in the sectoral allocation of labor. We also compare the transmission of a single period positive procurement shock with a single period negative productivity shock. We consider these two cases because they typify the kind of shocks experienced by the Indian agriculture sector (upward increase in procurement, a poor monsoon). For a positive productivity shock, we show that on impact, the economy experiences higher inflation, and a slightly negative output gap. Under a positive procurement shock, labor reallocates *away* from the manufacturing and the vegetable sector. Under a negative productivity shock, labor reallocates *towards* the manufacturing and vegetable sectors. In addition, the presence of procurement changes the standard NKPC and DIS curves of the aggregate economy. Under a sufficient condition, we show that the NKPC and DIS curves become steeper suggesting that the central bank's response to a terms of trade shock needs to be stronger. We also show that procurement weakens monetary policy transmission. Our paper contributes to a growing literature on monetary policy in India and other emerging market economies.

In this chapter, the role of government (fiscal policy) in stabilizing the economy is kept passive while only monetary policy is active. For future research a more rich framework for fiscal policy can be added to the present framework in the following ways: (1) Adding a government sector that redistributes grain to households explicitly. This would involve having heterogeneous agents which is beyond the scope of this dissetation. (2) Modelling procurement using a feedback rule. Here the government can procure and redistribute grain but optimize on buffer stock accumulation to stabilize inflation. (3) Adding distortionary taxes and public debt to the present model for analyzing monetary and fiscal policy interactions in a much richer framework.

Figures

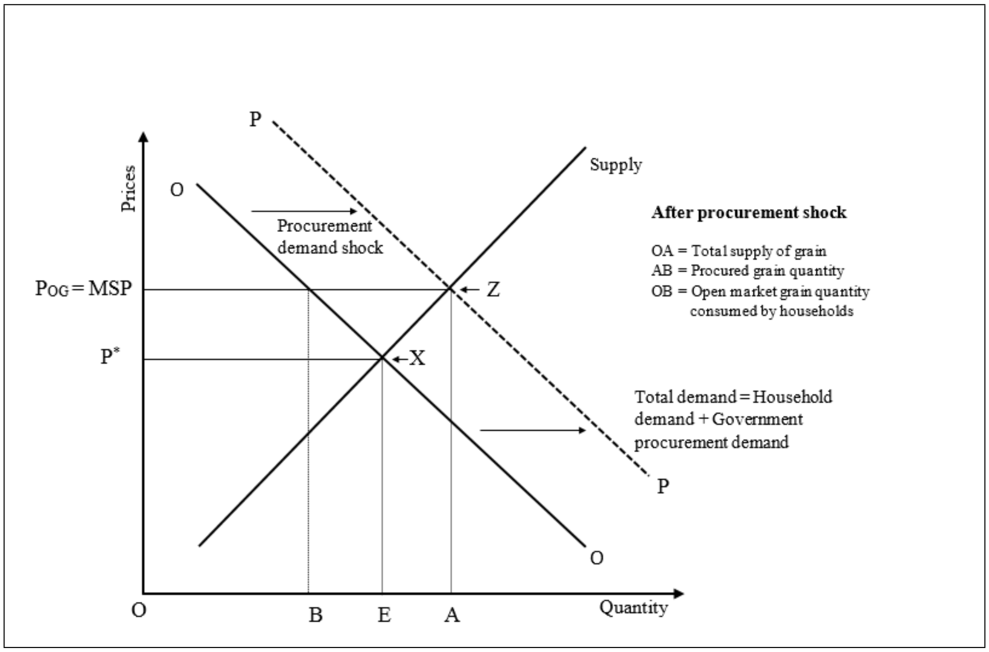

Figure 2-1: Effect of procurement policy on open market grain price and output

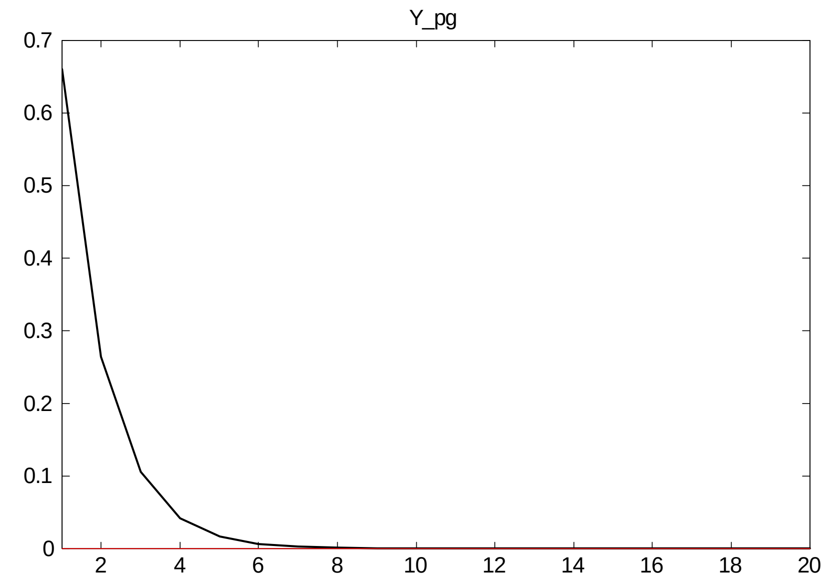

Figure 2-2: Impact of a single period positive procurement $\left(\widehat{Y}_{PG,t}\right)$ shock

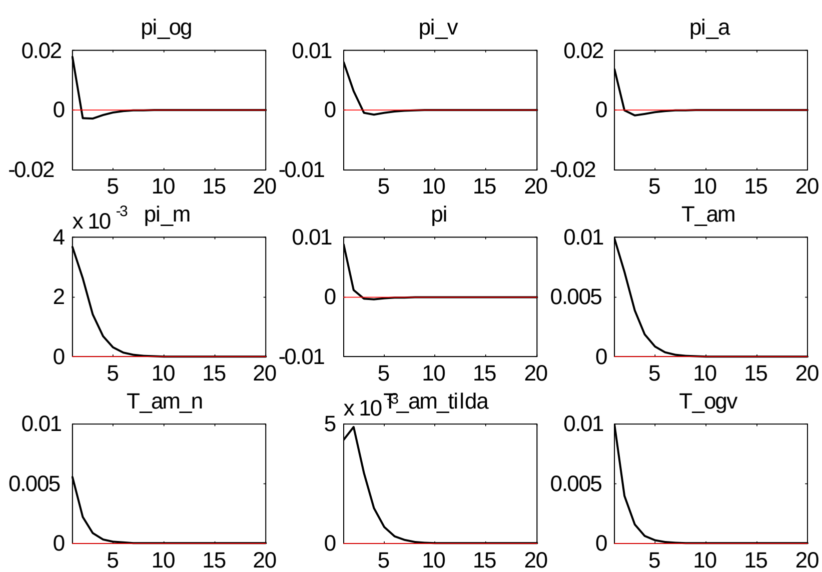

Figure 2-3: Impact of a single period positive procurement $\left(\widehat{Y}_{PG,t}\right)$ shock (contd.)

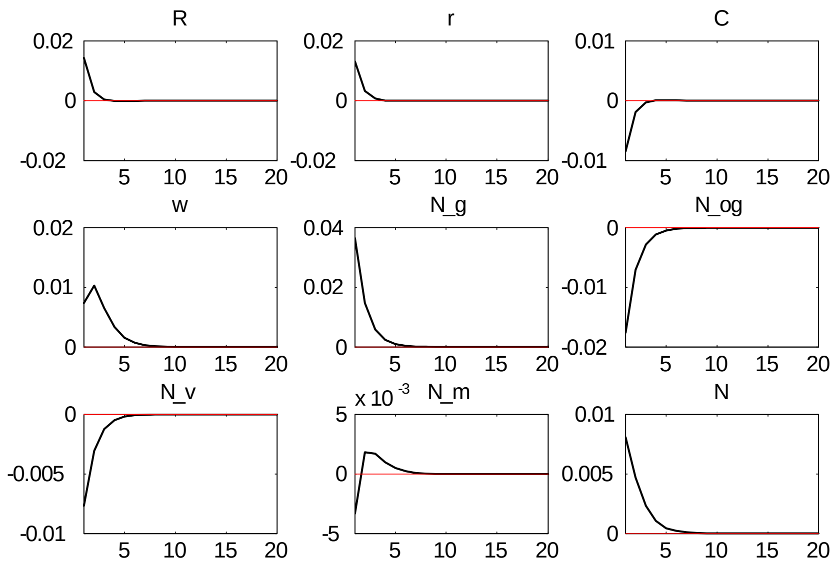

Figure 2-4: Impact of a single period positive procurement $\left(\widehat{Y}_{PG,t}\right)$ shock (contd.)

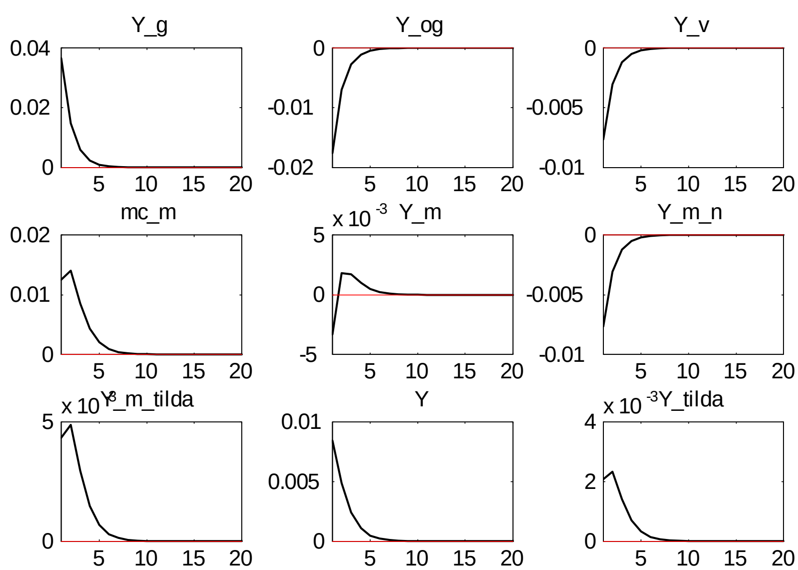

Figure 2-5: Impact of a single period positive procurement $\left(\widehat{Y}_{PG,t}\right)$ shock (contd.)

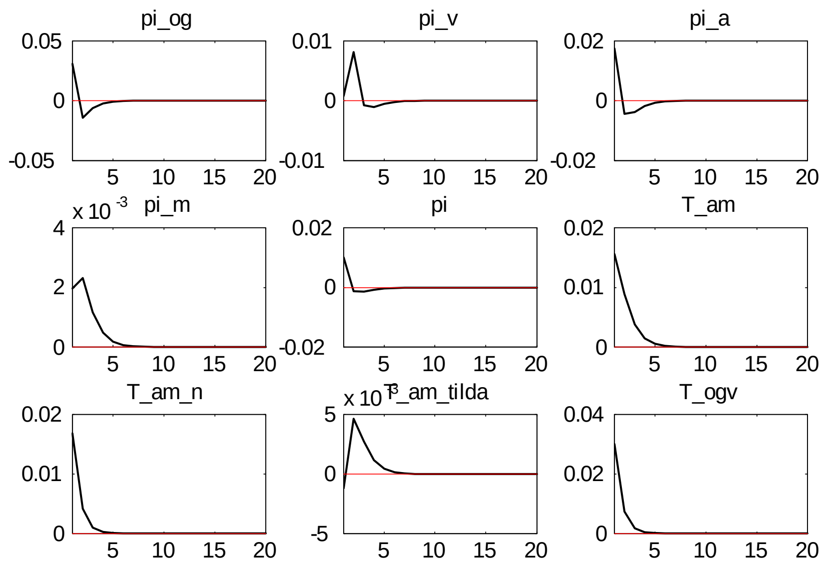

Figure 2-6: Impact of a single period negative productivity $\left(\widehat{A}_{G,t}\right)$ shock

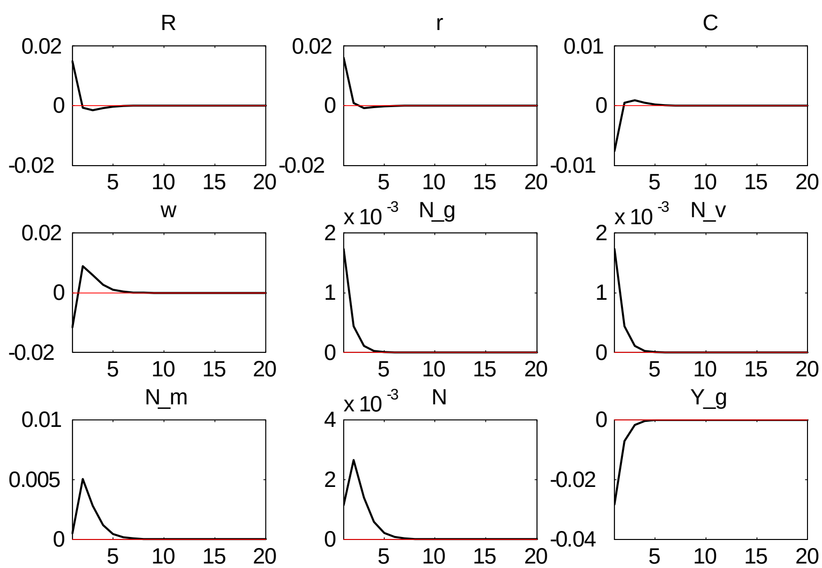

Figure 2-7: Impact of a single period negative productivity $\left(\widehat{A}_{G,t}\right)$ shock (contd.)

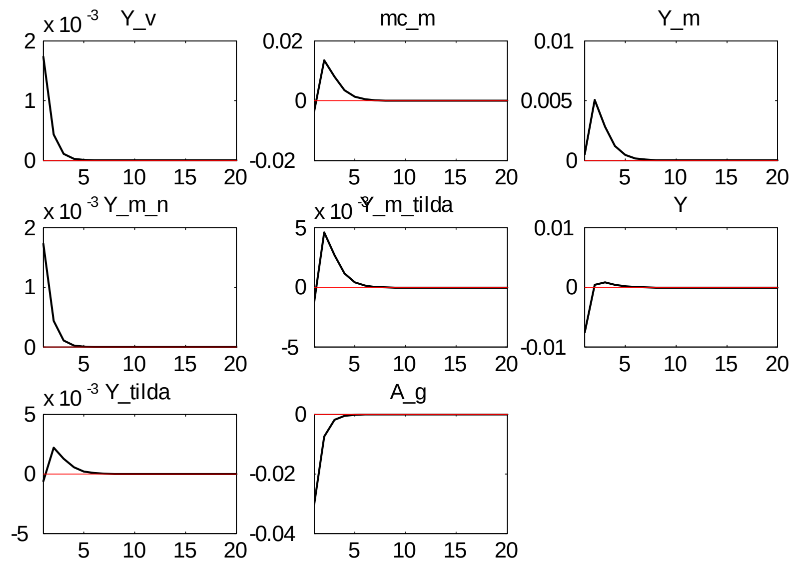

Figure 2-8: Impact of a single period negative productivity $\left(\widehat{A}_{G,t}\right)$ shock (contd.)

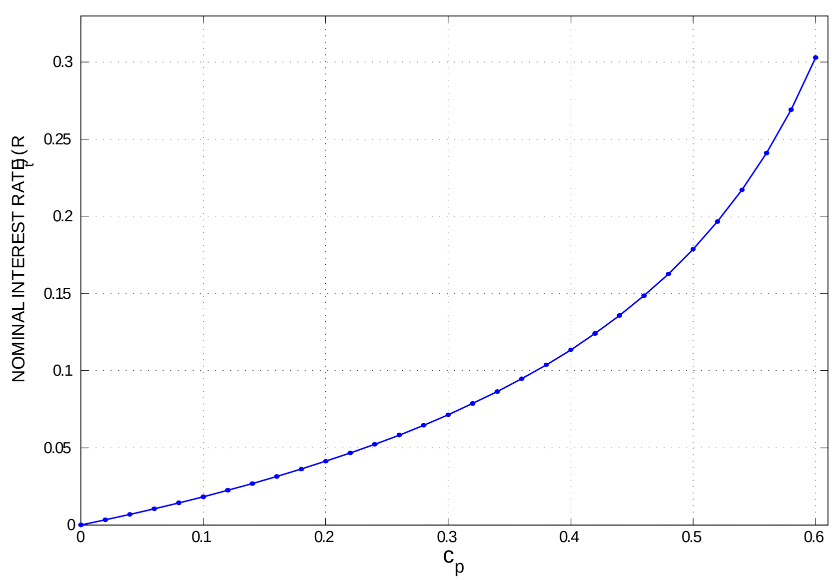

Figure 2-9: Monetary policy response $\left(\widehat{R}_t\right)$ and steady state share of procured grain (c_p)

Chapter 3

Inefficient Shocks and Optimal Monetary Policy

3.1 Introduction

Monetary policy in emerging markets and developing economies (EMDEs) is a challenging task as these economies are often characterized by inefficiencies such as incomplete financial markets, distorted agriculture sectors and large informal sectors that affect monetary policy effectiveness (see Hammond et al. (2009), Ghate and Kletzer (2016)). Most of the existing literature in monetary policy design for EMDEs focusses on determining an optimal inflation index that a central bank should target to reach a flexible price equilibrium.[1] In a recent paper, Anand et al. (2015) show that in EMDEs headline inflation targeting improves welfare outcomes by adding incomplete financial markets to the standard multi-sector small scale NK-DSGE model. This is different from Aoki (2001), who shows that *strict* core inflation targeting is an optimal monetary policy, to close the gap with a flexible price equilibrium, in developing countries, which are susceptible

[1] In this paper flexible price equilibrium is defined as an equilibrium level prevailing under complete price flexibility.

to sectoral relative price movements (or terms of trade shocks).[2] When occurrence of complete stabilization of inflation coincides with a complete stabilization of output, this is referred to as *divine coincidence* in the literature. In other words, there does not exists a trade-off in inflation and output gap stabilization. Aoki (2001) shows that divine coincidence occurs when monetary policy follows a strict core inflation targeting rule such that output gaps are also simultaneously stabilized.

One common aspect in the papers mentioned above is that they assume variations in the flexible price equilibrium are efficient.[3] However, there could be possibilities when variations in the flexible price equilibrium are not efficient and thus *strict* inflation targeting will not be an optimal monetary policy, as there exists a trade-off between inflation and output stabilization (see Woodford (2003), Chapter 6). In other words, any attempt to stabilize inflation would make output deviate further from its efficient allocation and any attempt to stabilize output would increase the variability of inflation. Even having a multi-sector Aoki type model with sectoral terms of trade shocks/ relative price shocks does not show any tension between core-inflation and output stabilization. Generally, inefficient variations in the flexible price equilibrium are modelled as inefficient supply shocks, such as a price/ wage mark-up shock (see Justiniano et al. (2013), Gilchrist et al. (2009), Gali et al. (2007), and Bhattarai et al. (2014)).[4] Kim and Henderson (2005) also show that optimal interest rate rules for strict inflation targeting regimes are suboptimal under both full and partial information.[5]

As an illustration, Figure 3-1 shows how an inefficient shock affects the output, Y, in the economy. When an inefficient shock hits the economy, the flexible price equilibrium, A, deviates from its efficient allocation, C. In this case, a monetary policy offsetting inflation and the gap between actual output and its flexible price equilibrium, AB, thus

[2] Also see Huang and Liu (2005), Benigno (2004) and Erceg and Levin (2006).

[3] In general, efficient equilibrium is defined as an equilibrium level prevailing under perfect competition.

[4] For the estimates of inflation/ output trade-offs in US see Fuhrer (1997). Gilchrist et al. (2009) shows trade-offs in the presence of financial frictions.

[5] They also show that some rules for flexible inflation targeting regime are optimal under partial information set.

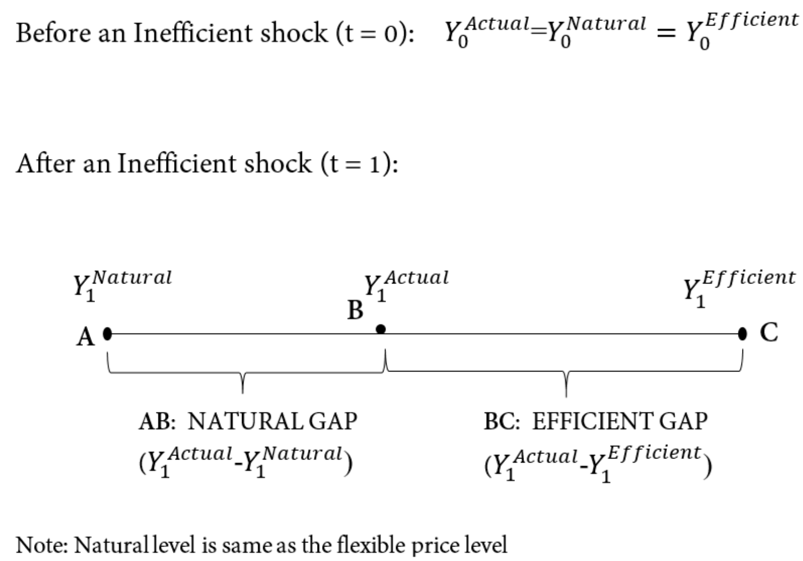

Figure 3-1: Flexible price equilibrium and efficient equilibrium with inefficient shocks

ends up increasing the gap of actual output from its efficient equilibrium from BC to AC. That is how inefficient shocks are the source of trade-off between inflation and the output gap stabilization. In Aoki (2001), the flexible price level coincides with the efficient allocation, thus these trade-offs do not occur.

Inefficient shocks do have a practical importance in monetary policy making but the sources of such shocks have not been studied much (Woodford (2003), p. 454).[6] This chapter addresses this gap in the literature and shows how real disturbances present in a developing economy could be a source of *inefficient* shocks. To be precise, in this chapter we identify market price support present in the agriculture sectors of EMDEs as an inefficient distortion and show its implications for optimal monetary policy design.

Market price support estimates (MPSE) in agriculture sector have been over 2.2 trillion US dollars, between 2011-2015, across the world (OECD (2016*a*)).[7] Out of the

[6]The term *real disturbance* refers to the existence of structural disturbances in the economy which can lead to trade-offs mentioned here. Generally in the New-Keynesian literature, the trade-off is generated with *exogenous* price/ wage mark-up shocks. What leads to such shocks is not studied much in the literature.

[7]The Organization for Economic Cooperation and Development (OECD) agriculture statistics

total producer support estimates (PSE) the share of MPSE is 55 per cent.[8] Market price supports primarily take two forms, i) border protection measures such as, tariffs, import quotas and export subsidies as in Canada, Colombia, European Union, Iceland, Israel, Kazakhstan, Korea, Mexico, Norway, Russia, Turkey, United States and Vietnam; and ii) target pricing of a commodity both with and without government purchases such as in China, India, Indonesia, Japan, Norway and Vietnam.[9]

In India and Indonesia, the target pricing of certain commodities is accompanied by government purchases of the commodity. This policy is known as a food grain procurement policy in India. Under this policy, the government announces the target price known as minimum support prices (MSP) for a variety of food grains before the cropping season starts. Once the harvest is done, the food grain producers sell their output to the government at a set MSP. The procured food grain is then stored in Food Corporation of India (FCI) warehouses. A part of the procured food grain is subsequently distributed to the poor at subsidized prices through the public distribution system (PDS). The remaining procured grain remains in warehouses as part of a buffer stock.

There is an extensive literature studying the effects of agricultural price supports on output, consumption and trade (see Bale and Lutz (1981), Anderson and Hayami (1986), Acemoglu and Robinson (2001), Timmer (1989), Dewbre et al. (2001), Benjamin and Talab (2011)). Figure 3-2 below shows the share of market price support as a percentage of GDP for EMDEs and advanced economies (AEs). As can be seen, between 2011-2015, the share for EMDEs is 0.78 per cent, which is almost double the share in AEs (which

database has agriculture support data for only 50 countries. The Market Price Support (MPS) is defined by OECD as an indicator of the annual monetary value of gross transfers from consumers and taxpayers to agricultural producers arising from policy measures creating a gap between domestic market prices and border prices of a specific agricultural commodity measured at the farm-gate level.

[8]The Producer Support Estimate (PSE) is defined by OECD as an indicator of the annual monetary value of gross transfers from consumers and taxpayers to support agricultural producers, measured at the farm gate level, arising from policy measures, regardless of their nature, objectives or impact on farm production or income. Total PSE are over 4 trillion US dollars between 2011-2015.

[9]Refer to OECD (2016*b*) for each country (except India) to get more detailed analysis. For India refer to OECD (2009). Under target pricing, Indonesia and India have target/ support prices with government purchases and China, Japan, Norway and Vietnam have target/ support prices without government procurement.

is 0.40 per cent).[10] What accentuates the effect of market price support in EMDEs are large agriculture sectors. Figure 3-3 below shows the share of the agriculture sector as a percentage of GDP between 2011-2015 for EMDEs and AEs. The share is 13.4 per cent and 1.8 per cent for EMDEs and AEs respectively.[11]

[INSERT FIGURES 3-2 & 3-3]

The effects of government induced procurement policy on the macroeconomy of India are non-negligible.[12] In recent years, rising minimum support prices has fueled food inflation in India (see Anand et al. (2016), Basu (2011), Dev and Rao (2015), Ramaswami et al. (2014), Ghate et al. (2018)). High food inflation is a cause for concern, especially in a developing country like India where food expenditure shares are very high. For instance, the share of food in consumer expenditure is 52.9% and 42.6% in rural and urban India, respectively (NSS (National Sample Survey) 68^{th} Round $(2011-12)$).[13] Mishra and Roy (2011) and Shekhar et al. (2017) show that minimum support prices and excess procurement by the government with huge unsold stocks is an important factor driving food inflation and food price volatility especially for cereals. Chapter 2 has shown how the incidence of market price support in the agriculture sector of India leads to sectoral and aggregate inflation, output gaps and resource reallocation using a multi-sector NK-DSGE model. We introduce a procurement inefficiency in the food grain

[10] The author has used OECD agriculture statistics database (doi: dx.doi.org/10.1787/agr-pcse-data-en (accessed on 16 June, 2017). According to the data, advanced economies (AE) constitute the United States, European Union (28 countries), Australia, Canada, Iceland, Israel, Japan, Korea, New Zealand, Norway and Switzerland. Emerging markets and developing economies (EMDEs) constitute, Brazil, Chile, China, Colombia, Indonesia, Kazakhstan, Mexico, Russia, South Africa, Turkey, Ukraine and Vietnam.

[11] The figures are calculated by the author using *Macro Indicators Data* available on the Food and Agriculture Organization of the United Nations (FAO) (http://www.fao.org/faostat/en/#data/MK accessed in June, 2017). The percentage figures 13.4% and 1.8% are the share of value of agriculture, fishing and forestry in GDP on average for EMDEs (152 countries) and AEs (38 countries) respectively, between 2011-2015. The author uses the International Monetary Fund's (IMF) categorization of AE and EMDEs (WEO (2016), October 2016).

[12] Ramaswami et al. (2014) show that the accumulated welfare losses of procurement policy to the Indian economy between 1998 and 2011 was 1.5 billion US dollars.

[13] The food subsidy bill rose by 300% between 2006-07 and 2011-12 in India (see Sharma and Alagh (2013)).

sector as a shock and discuss the transmission of such a shock to the aggregate economy. We also show that these shocks weaken monetary policy transmission.

In this chapter, using the NK-DSGE model built in Chapter 2 we derive the welfare loss function for a central bank of an economy, characterized by market price support. Although we build on the NK-DSGE model specific to the Indian economy, the results can be generalized to other EMDEs featuring similar inefficiencies. To derive the welfare loss function we follow Rotemberg and Woodford (1997), Rotemberg and Woodford (1999), Woodford (1999) and Woodford (2003). To recap, model has three sectors: grain, vegetable and a manufacturing sector. The grain and vegetable sectors are part of the flexible price agriculture sector. The manufacturing sector is a sticky price sector. The model features a procurement inefficiency in the flexible price sector namely, the grain sector. Using a welfare loss function, we characterize optimal monetary policy under discretion and commitment and study how trade-offs between inflation and output gap stabilization get affected in the presence of a procurement inefficiency. We then compare and rank optimal monetary policy rules with some implementable rules.

To summarize, this chapter attempts to incorporate real structural challenges in EMEs within the current modelling framework of monetary policy design and derive optimal monetary policy rules for more effective policy implementation. The structural challenge we consider here is a real disturbance in the form of a market price support in the agriculture sector of EMEs. We show that a government induced procurement policy is a source of inefficient shocks for an economy and it generates a trade-off for optimal monetary policy design.

3.1.1 Main Results

We find that the inefficiency due to procurement in the agriculture sector affects the economy through two distinct channels. First, it raises prices in the grain sector by affecting price mark-ups. Second, by reducing aggregate consumption directly, it deprives households of a part of the output. These channels lead to variations in the flexible-price equilibrium which are not efficient. The derived welfare loss function is a function of squares of core-inflation, the consumption gap, and the terms of trade gap, where gaps are not the *natural gaps* (from the flexible-price equilibrium) but from an efficient equilibrium. For the model economy, an efficient equilibrium with procurement is defined as a flexible-price equilibrium with no mark-up effect of the procurement inefficiency i.e. without the first channel mentioned above. In a standard model, the squares of the consumption gaps coincide with the output gap and the welfare loss function is written as a function of output gaps. Here, because of the second channel, procurement creates a wedge between consumption and output and consumption gaps no longer equal to the output gap.

Optimal monetary policy under discretion and commitment show that a central bank cannot stabilize core-inflation, output gap and terms of trade gap simultaneously, as there exists a *trade-off* between core-inflation and output gap stabilization and between the terms of trade gap and output gap stabilization. Due to this, the minimum possible welfare losses are not zero. This happens due to a presence of the procurement inefficiency which makes the flexible price equilibrium of the model economy deviate from its efficient allocation. Thus, any attempt to bring core-inflation to zero makes output deviate from its efficient allocation. We show that divine coincidence does not exist in the presence of procurement. This result departs from Aoki (2001), who shows that there exists divine coincidence and welfare losses can be minimized to zero with complete core-inflation stabilization for developing countries featuring sectoral relative price movements. We also produce *efficient policy frontiers* (EPF) for the optimal policy rules (for both discretion and commitment) to calibrate trade-offs for the model economy described in Chapter 2.

We compare the response of the economy under different optimal and implementable Taylor type interest rate rules when an economy is hit by a positive procurement shock and a negative productivity shock. A comparative analysis among different monetary policy rules shows that an optimal interest rate rule under commitment gives the least welfare losses and is thus the best among all considered monetary policy rules. Within the class of implementable monetary policy rules, a simple Taylor rule with target variables as inflation and the output gap, performs the worst. The welfare losses reduce significantly when terms of trade gaps are added to a simple Taylor rule. We also find optimal coefficients on a simple Taylor rule with terms of trade gaps to obtain an *optimal simple rule* (OSR) for the economy. It is observed that an optimal simple rule with sectoral terms of trade/ relative price gaps improves welfare outcomes significantly. In particular, welfare losses reduce by 21 per cent and 62 per cent with optimal simple rules for a positive procurement shock and a negative productivity shock, respectively.

3.2 The welfare loss function

We derive the welfare loss function for the model described in Chapter 2, to analyze implications of a procurement inefficiency on an optimal monetary policy. We take a second order approximation of the discounted sum of utility flows incurred by a representative consumer in a rational expectations equilibrium.[14] The approximation to utility for welfare derivation is taken from its efficient allocation equilibrium. The gap of the actual level of a variable realized after the shock from its flexible price equilibrium is referred to as a *natural gap*, and a gap of actual levels realized after a shock from its efficient level equilibrium is referred to as an *efficient gap*.[15] A standard one sector NK-DSGE model has two sources of inefficiencies namely, a sticky price sector (nominal rigidity) and monopolistically competitive firms with constant mark-ups (real rigidity).[16] In such a model, if the government provides an appropriate employment subsidy to the firms to do away with the inefficiency due to monopolistic competition (no real rigidity), the flexible price equilibrium (no nominal rigidity) coincides with the efficient allocation,

[14]We use seminal work of Rotemberg and Woodford (1997), Rotemberg and Woodford (1999), Woodford (1999) and Woodford (2003).

[15]Note this is important here because model equations like the NKPC and the dynamic-IS curve are written in terms of natural gaps. If the welfare loss function is in terms of efficient gaps, then some modifications need be done to them to derive optimal rules using the derived welfare losses.

[16]See Chapter-3, Gali (2008)

such that the natural gaps are the same as the efficient gaps. Now, if an economy is characterized by price/wage markup time-varying shocks (generally referred to as *inefficient* supply shocks), a flexible price allocation does not coincide with the efficient one.[17] Hence natural gaps are not the same as the efficient gaps.

In the present model as described in Chapter 2 there are three sources of inefficiencies namely, sticky prices in the manufacturing sector (nominal rigidity), monopolistic competition (real rigidity 1) and a procurement distortion (real rigidity 2). We do away with the market power distortion completely in the vegetable and manufacturing sector and partially in the grain sector by giving an appropriate employment subsidy. A fixed employment subsidy, $(1-\tau)=\frac{\theta-1}{\theta}$, is provided to neutralize the effect of market power in all three sectors. Mark-ups in the grain sector as shown in equation (2.27) are scaled up by the presence of procurement and become time-varying. Thus, a fixed employment subsidy does not remove the market power completely in the grain sector. Without a procurement distortion and with an employment subsidy the flexible price equilibrium in the model coincides with the efficient equilibrium, but with procurement we have a different scenario. Procurement of grain by the government impacts an economy by two channels. First, procurement raises prices in the grain sector and affects the mark-up as shown in equation (2.27). Second, procurement reduces aggregate consumption directly, as it deprives households of a part of the output produce, as shown in equation (2.34). In this section, we shall see how the welfare loss function gets affected when a sector in the economy is characterized with a procurement distortion. For deriving the welfare function, we assume that a continuum of households exist on $[0,1]$ and a representative household supplies labour type i to sector s and maximizes,

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[U(C_t) - v(N_{S,t}(i))\right]$$

where s represents the sector to which a household supplies labour, such that $s=G,V,M$

[17]See Bhattarai et al. (2014) and Chapter-6, Woodford (2003).

for grain, vegetable and manufacturing sector, respectively. Writing the utility function this way does not affect the results described in Chapter 2 as labour was assumed to be homogeneous. Also, the household's consumption basket is the same and the nominal wage in equilibrium is the same across three sectors in the basic framework of the model described in Chapter 2. [18] The labour supplied to each sector depends on the share of each sector in aggregate output. Following this, $\delta(1-\mu)$ proportion of households supply their labour to the grain sector, $\delta\mu$ to the vegetable sector and remaining $(1-\delta)$ to the manufacturing sector. Average utility in the economy at time t is defined as,

$$w_t = U(C_t) - \frac{1}{\delta(1-\mu)} \int_0^{\delta(1-\mu)} v(N_{G,t}(i))di - \frac{1}{\delta\mu} \int_{\delta(1-\mu)}^{\delta} v(N_{V,t}(i))di - \frac{1}{(1-\delta)} \int_{\delta}^{1} v(N_{M,t}(i))di \tag{3.1}$$

where $U(C_t)$ is the utility from the aggregate consumption bundle C_t, and $v(N_{G,t}(i))$, $v(N_{V,t}(i))$ and $v(N_{M,t}(i))$ denotes the disutility of supplying labour to the grain sector, vegetable sector and manufacturing sector respectively. The welfare loss function is thus given by,

$$W_t = -E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{w_t - w}{U_C\, C} \right) \tag{3.2}$$

where w is the steady state of average utility described in equation (3.1). We take a second order approximation of the average utility flow as described in equation (3.1) to get an expression for the welfare loss function around a distorted steady state. The presence of a procurement inefficiency distorts the consumption-leisure choice decision at the steady state. The ratio of marginal disutility from labour supply to marginal utility from consumption in the presence of procurement is defined as,

$$\frac{V_Y}{U_C} = \boldsymbol{\gamma}^{(1-\mu)\delta},$$

where $\gamma \neq 1$. In the absence of a procurement inefficiency $\gamma = 1$ and $\frac{V_Y}{U_C} = 1$. To get this

[18] The budget constraint also remains the same and the first order conditions do not change.

we assume that the government gives an employment subsidy $(1-\tau)=\frac{\theta-1}{\theta}$. A second order approximation of w_t gives the following expression,[19]

$$
\begin{aligned}
w_t \;\approx\; & -\frac{U_C\, C}{2}\left[(1-\delta)\left(\theta^{-1}+\psi\right)\theta^2 Var\left\{\widehat{P}_{M,t}(i)\right\}+2\beta_{2C}\left(\widehat{C}_t-\widehat{C}_t^{*}\right)^2+\right.\\
& \left.+2\beta_{2TAM}\left(\widehat{T}_{AM,t}-\widehat{T}^{*}_{AM,t}\right)^2\right]\\
& +\|O\|^3+t.i.p.
\end{aligned}
$$

where, $\widehat{C}_t^{*}=\frac{\beta_{1C}}{2\beta_{2C}}$ and $\widehat{T}^{*}_{AM,t}=\frac{\beta_{ITAM}}{2\beta_{2TAM}}$ are the efficient allocations of consumption and the terms of trade (between the agriculture and manufacturing sector), respectively. The expressions in the denominator, β_{2C} and β_{2TAM}, are composites of parameters.[20] The expressions in the numerator of the efficient levels, β_{1C} and β_{1TAM}, are a function of shocks and natural level of the variables.[21]

Efficient allocations of variables are a function of shocks similar to the flexible price allocation. From the above definition we observe that the efficient allocations we obtain from approximating utility flows depends on procurement as well. This happens because procurement reduces utility of a representative household in two ways, (i) by reducing real consumption as procurement shocks increase the price of the consumption bundle (mark-up channel); (ii) by reducing consumption directly as the government procures a certain proportion of the good from the consumption basket (quantity channel).[22] A

[19] A detailed derivation of the welfare loss function is provided in the Technical Appendix B.1.

[20] $\beta_{2C}=-\frac{1}{2}(1-\sigma)+(\alpha_{2V}+\alpha_{2M}+\alpha_{2G})$, and $\beta_{2TAM}=\left(\alpha_{2M}\delta^2+\alpha_{2V}(1-\delta)^2+\alpha_{2G}(1-\delta)^2\right)-\left(2\alpha_{2G}(1-\delta)\mu-2\alpha_{2V}(1-\delta)(1-\mu)\right)\widehat{T}_{OGV,t}+(1-\delta)\left(2\alpha_{2M}\delta-2\alpha_{2V}(1-\delta)-2\alpha_{2G}(1-\delta)\right)$

Here, α_{2G}, α_{2V} and α_{2M} are also composites of parameters and are given by, $(1-\mu)\,\delta\gamma\left(\frac{1+\psi(1-c_p)}{2}\right)$, $\mu\delta\left(\frac{\psi+1}{2}\right)$ and $(1-\delta)\left(\frac{\psi+1}{2}\right)$, respectively.

[21] $\beta_{1C}=(\alpha_{1V}+\alpha_{1M}+\alpha_{1G})-\left(2\alpha_{2V}(1-\mu)-2\alpha_{2G}\mu\right)\widehat{T}^{n}_{OGV,t}$, and $\beta_{1TAM}=\left(\alpha_{1M}\delta-(1-\delta)(\alpha_{1V}+\alpha_{1G})\right)-\left(2\alpha_{2M}\delta-2\alpha_{2V}(1-\delta)-2\alpha_{2G}(1-\delta)\right)\left(\widehat{Y}^{n}_{V,t}-(1-\mu)\,\widehat{T}^{n}_{OGV,t}\right)-\left(2\alpha_{2G}(1-\delta)\mu-2\alpha_{2V}(1-\delta)(1-\mu)\right)\widehat{T}_{OGV,t}$, Further, α_{1G}, α_{1V}, α_{1M} are too a function of shocks and are given by, $(1-\mu)\,\delta\left(\gamma\psi\left(g_{OG,t}(1-c_p)-g_{PG,t}c_p\right)+(1-\gamma)\right)$, $\mu\delta\psi g_{V,t}$, and $(1-\delta)\,\psi g_{M,t}$, respectively. We define, $g_{OG,t}=-\frac{V_{Y_{OG}A_V}}{V_{Y_{OG}Y_{OG}}Y_{OG}}\widehat{A}_{G,t}$, $g_{PG,t}=-\widehat{Y}_{PG,t}$, $g_{V,t}=-\frac{V_{Y_V A_V}\widehat{A}_{V,t}}{V_{Y_V Y_V}Y_V}$ and $g_{M,t}=-\frac{V_{Y_M A_M}\widehat{A}_{M,t}}{V_{Y_M Y_M}Y_M}$.

[22] The channel through which procurement shocks lead to an increase in consumer price inflation has

central bank's monetary policy can only minimize/ eliminate a price/ mark-up channel effect because of a procurement shock. Monetary policy cannot affect the direct reduction in consumption due to procurement. Thus, an efficient equilibrium of an economy with procurement has no mark-up effect because of procurement but still has quantity effects. Both these effects are absent only in an efficient equilibrium of the economy without procurement.

As an illustration, Figure 3-4 below shows the efficient and flexible price equilibrium for the output, consumption and the terms of trade (both between agriculture and manufacturing sector and between open grain and vegetable sector) when procurement is present $(c_p > 0)$ and when procurement is absent $(c_p = 0)$.[23] It can be seen that, the efficient and flexible price equilibrium does not coincide when procurement is positive. The efficient equilibrium with $(c_p > 0)$ and without $(c_p = 0)$ procurement is different for the reasons mentioned above.

[INSERT FIGURE 3-4]

Finally to get a following approximated sum of lifetime welfare losses, we substitute w_t from equation (3.1) above in equation (3.2) and further simplify,

$$\begin{aligned} W_t &= -E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{w_t}{U_C \; C} \right) \approx \frac{1}{2} \lambda_{\pi M} E_0 \sum_{t=0}^{\infty} \beta^t \left[\pi_{M,t}^2 + \frac{\lambda_{\widetilde{C}}}{\lambda_{\pi M}} \left(\widetilde{C}_t^* \right)^2 + \right. \\ & \left. + \frac{\lambda_{\widetilde{TAM}}}{\lambda_{\pi M}} \left(\widetilde{T}_{AM,t}^* \right)^2 \right] + \|O\|^3 + t.i.p. \end{aligned} \tag{3.3}$$

The average welfare loss per period is given by the following linear combination of variances of the consumption gap, core inflation and terms of trade,

$$L_t = \pi_{M,t}^2 + \frac{\lambda_{\widetilde{C}}}{\lambda_{\pi M}} \left(\widetilde{C}_t^* \right)^2 + \frac{\lambda_{\widetilde{TAM}}}{\lambda_{\pi M}} \left(\widetilde{T}_{AM,t}^* \right)^2 \tag{3.4}$$

been explained in Chapter 2 in detail.

[23]We use calibrated parameters from Table 2.2 in Chapter 2 for this exercise.

where, $\widetilde{C}_t^* = \left(\widehat{C}_t - \widehat{C}_t^*\right)$, and $\widetilde{T}_{AM,t}^* = \left(\widehat{T}_{AM,t} - \widehat{T}_{AM,t}^*\right)$ are gaps from their efficient allocation (efficient gaps). Also, $\lambda_{\pi M} = \frac{\alpha_M(1-\delta)\left(\theta^{-1}+\psi\right)\theta^2}{(1-\beta\alpha_M)(1-\alpha_M)}$, $\lambda_{\widetilde{C}} = 2\beta_{2C}$ and $\lambda_{\widetilde{TAM}} = 2\beta_{2TAM}$. In the presence of procurement shocks, the consumption gap from its efficient level is not the same as the output gap from its efficient level. The relation between the two is given by following equation,

$$\widetilde{Y}_t^* = (1-\lambda_c)\widetilde{C}_t^* + \lambda_c(1-\delta)\widetilde{T}_{AM,t}^* - (1-\lambda_c)z_{1,t}^* \tag{3.5}$$

where

$$z_{1,t}^* = \frac{1}{(1-\lambda_c)}\left(\widehat{Y}_t^* - \widehat{Y}_t^n\right) - \left(\widehat{C}_t^* - \widehat{C}_t^n\right) - \frac{\lambda_c(1-\delta)}{(1-\lambda_c)}\left(\widehat{T}_{AM,t}^* - \widehat{T}_{AM,t}^n\right), \tag{3.6}$$

The quadratic welfare loss function in equation (3.4) is different from a standard loss function of a multiple sector model of Aoki (2001) in two distinct ways.[24] First, in Aoki (2001) welfare losses are a function of the variance of core inflation, $\pi_{M,t}$, the output gap, $\widetilde{Y}_t^*$, and the terms of trade gaps, $\widetilde{T}_{AM,t}^*$, where output gaps are the same as consumption gaps, $\widetilde{C}_t^*$.[25] The welfare loss function in equation (3.4) has a variance of consumption gap, $\widetilde{C}_t^*$, instead of the output gap, $\widetilde{Y}_t^*$. This happens because procurement takes away a certain proportion of grain sector goods ($\lambda_c > 0$) such that in the aggregate goods market equilibrium consumption does not equals output. The output gap, $\widetilde{Y}_t^*$, is related to the consumption gap, $\widetilde{C}_t^*$, through equation (3.5). Second, since an efficient equilibrium is not the same as a flexible price equilibrium, for the reasons explained above, efficient gaps of the variables in the welfare function are not the same as natural gaps. In the case of Aoki (2001) natural gaps are same as efficient gaps, as inefficient shocks are not modelled there.[26]

[24] Also see Huang and Liu (2005) and Benigno (2004) for standard welfare loss function in a closed economy multiple-sector and a two-country NK-DSGE model, respectively.

[25] A standard form of the welfare loss function depends on the squares of inflation and output gap.

[26] The coefficients in front of $\left(\widetilde{C}_t^*\right)^2$ and $\left(\widetilde{T}_{AM,t}^*\right)^2$ in the derived welfare loss function are also different from Aoki (2001), as they are a composite of procurement parameter, c_p.

Proposition 1 *In absence of procurement shocks in the grain sector i.e. when $c_p = 0$, the efficient level equilibrium of a model economy is identical to the flexible price equilibrium. In other words, when $c_p = 0$, $\widehat{C}_t^* = \widehat{C}_t^n$, $\widehat{T}_{AM,t}^* = \widehat{T}_{AM,t}^n$, $z_{1,t}^* = 0$ and consumption gaps are same as output gaps, such that the quadratic welfare loss function matches with Aoki* (2001).

Proof. See Technical Appendix B.2 for a complete proof.[27] Here it suffices to say when $c_p = 0$, the flexible price equilibrium, defined in Section 2.3.3 of Chapter 2, and an efficient level equilibrium, defined above, reduces to,

$$\widehat{C}_t^* = \widehat{C}_t^n = \frac{(\psi+1)}{(\psi+\sigma)}\left[\mu\delta\widehat{A}_{V,t} + (1-\delta)\widehat{A}_{M,t} + (1-\mu)\delta\widehat{A}_{G,t}\right] \tag{3.7}$$

$$\widehat{T}_{AM,t}^* = \widehat{T}_{AM,t}^n = \widehat{A}_{M,t} - (1-\mu)\widehat{A}_{G,t} - \mu\widehat{A}_{V,t} \tag{3.8}$$

$$\widehat{T}_{OGV,t}^* = \widehat{T}_{OGV,t}^n = \widehat{A}_{V,t} - \widehat{A}_{G,t} \tag{3.9}$$

From the goods market equilibrium, an efficient and flexible price levels for the aggregate output is given by,

$$\widehat{Y}_t^* = (1-\lambda_c)\widehat{C}_t^* + \lambda_c[\widehat{Y}_{PG,t} + \mu\widehat{T}_{OGV,t}^* + (1-\delta)\widehat{T}_{AM,t}^*],$$

and

$$\widehat{Y}_t^n = (1-\lambda_c)\widehat{C}_t^n + \lambda_c[\widehat{Y}_{PG,t} + \mu\widehat{T}_{OGV,t}^n + (1-\delta)\widehat{T}_{AM,t}^n],$$

respectively. From Chapter 2, $\lambda_c = \gamma^{\delta(1-\mu)-1}c_p s_g$. Thus $c_p = 0$ implies $\lambda_c = 0$. The goods market equilibrium thus reduces to $\widehat{Y}_t^* = \widehat{C}_t^*$ and $\widehat{Y}_t^n = \widehat{C}_t^n$. Using equation (3.5), we get $\widetilde{Y}_t^* = \widetilde{C}_t^* = \widetilde{Y}_t = \widetilde{C}_t$, when $c_p = 0$. Here $\widetilde{Y}_t, \widetilde{C}_t$ signify gaps in actual output and consumption from their flexible price equilibrium counterparts, as defined in Chapter 2. The quadratic welfare loss function thus becomes

$$L_t = \lambda_{\pi M}(\pi_{M,t})^2 + (\sigma+\psi)\left(\widetilde{Y}_t\right)^2 + (\psi+1)(1-\delta)\delta\left(\widetilde{T}_{AM,t}\right)^2$$

[27]We consider that demand shocks are absent, here such that $\widehat{\Gamma}_t = 0$.

This welfare loss function is similar to the loss function in a multi-sector model as derived in Aoki (2001). ■

3.3 Optimal monetary policy

This section will discuss monetary policy rules that minimize the welfare loss function described above. A monetary policy rule that minimizes the welfare loss function is termed as an optimal monetary policy. We will characterize optimal monetary policy under discretion and commitment for our model economy in following Section 3.3.1 and 3.3.2, respectively.

3.3.1 Optimal monetary policy under discretion

The optimal monetary policy under discretion is a policy where the monetary authority optimizes on its decision in each period without committing itself to any future actions.[28] Formally the problem can be written as,

$$\min_{\{\pi_{M,t},\, \widetilde{C}_t^*,\, \widetilde{T}_{AM,t}^*,\}} \frac{1}{2}\left[\pi_{M,t}^2 + \frac{\lambda_{\widetilde{C}}}{\lambda_{\pi M}}\left(\widetilde{C}_t^*\right)^2 + \frac{\lambda_{\widetilde{TAM}}}{\lambda_{\pi M}}\left(\widetilde{T}_{AM,t}^*\right)^2\right]$$

subject to the NKPC,

$$\pi_{M,t} = \beta E_t\left\{\pi_{M,t+1}\right\} + \lambda_M\left(\sigma + \psi\Theta_1\right)\widetilde{C}_t^* + \lambda_M \delta \widetilde{T}_{AM,t}^* + z_{2,t}^*. \tag{3.10}$$

where,

$$z_{2,t}^* = \lambda_M\left(\sigma + \psi\Theta_1\right)\left(\widehat{C}_t^* - \widehat{C}_t^n\right) + \lambda_M \delta\left(\widehat{T}_{AM,t}^* - \widehat{T}_{AM,t}^n\right). \tag{3.11}$$

The above NKPC constraint equation (3.10) is different from the NKPC equation (2.60b) in Chapter 2, as the above NKPC is in terms of efficient gaps.[29] Using the first order

[28]Refer to the Technical Appendix B.4 for detailed derivations.
[29]Refer to the Technical Appendix B.3 for details.

conditions from the above optimization and the aggregate output gap equation (3.5), we get the following *targeting rules*[30],

$$\pi_{M,t} = -\frac{1}{X_1(1-\lambda_c)}\widetilde{Y}_t^* - \frac{1}{X_1}z_{1,t}^* \tag{3.12}$$

$$\pi_t = -\frac{X_2}{X_1(1-\lambda_c)}\widetilde{Y}_t^* - \frac{X_2}{X_2X_1}z_{1,t}^* + z_{3,t}^* - \frac{\delta^2\lambda_M\lambda_{\pi M}}{\lambda_{\widetilde{TAM}}}\pi_{M,t-1} \tag{3.13}$$

$$\pi_{M,t} = -\frac{\lambda_{\widetilde{TAM}}}{\delta\lambda_M\lambda_{\pi M}}\widetilde{T}_{AM,t}^* \tag{3.14}$$

where X_1 and X_2 are combinations of parameters and $z_{3,t}^* = \Delta\widehat{T}_{AM,t}^*$.

Proposition 2 *In the presence of a procurement distortion, $c_p > 0$, there exists a trade off in stabilizing core inflation and the output gap i.e. no divine coincidence exists with optimal monetary policy under discretion. Divine coincidence only occurs when the procurement distortion is absent i.e. $c_p = 0$.*

Proof. It has been discussed in detail in Section 3.2 that with the presence of procurement, $c_p > 0$, an efficient equilibrium is different from a flexible price equilibrium, such that $z_{1,t}^* \neq 0$ in equation (3.6) . In a targeting rule for optimal monetary policy under discretion, as described in equation (3.12), when $z_{1,t}^* \neq 0$ it is not possible to achieve, $\pi_{M,t} = 0$ and $\widetilde{Y}_t^* = 0$, simultaneously.[31] In other words, a central bank cannot stabilize core-inflation and the output gap together. When a central bank puts higher weight on inflation stabilization and completely stabilizes core inflation i.e. $\pi_{M,t} = 0$, the minimum output gap in the economy, $\widetilde{Y}_t^*$, would be $-(1-\lambda_c)z_{1,t}^*$. Similarly, if a central banks puts higher weight on output gap stabilization and closes the gap of output from its efficient level, such that $\widetilde{Y}_t^* = 0$, the minimum core inflation in the economy would be $-\frac{1}{X_1}z_{1,t}^*$. The extent of trade-off would depend on the size of the procurement shock. Higher the

[30] A targeting rule is the relation between target variables that a central bank seeks to maintain at all times. We do the welfare loss minimization keeping $E_t\{\pi_{M,t+1}\}$ as given.

[31] It is also not possible to achieve $\widetilde{T}_{AM,t}^* = 0$ and $\widetilde{Y}_t^* = 0$, simultaneously.

size of the shock, higher would be the gap between the efficient equilibrium and flexible price equilibrium, such that $z^*_{1,t}$, would be higher. Since core-inflation and output cannot be stabilized simultaneously, we do not have divine coincidence, instead, there exists a trade-off in stabilizing core-inflation and the output gap.

Following, Proposition 1, when $c_p = 0$, the efficient equilibrium coincides with the flexible price equilibrium, such that $z^*_{1,t} = 0$ and it is possible to have $\pi_{M,t} = 0$ and $\widetilde{Y}^*_t = 0$, simultaneously. Thus, divine coincidence follows. ■

At this point we depart with Aoki (2001), where it is shown that strict core inflation targeting is an optimal monetary policy for developing countries, given that these countries are susceptible to terms of trade shocks. This departure happens because a developing country like India is characterized with many sector specific inefficiencies. In this chapter we explore the effects of a government induced procurement distortion present in the agriculture sector. A procurement policy generates these trade-offs because of its role as a structural feature. The structural presence of procurement increases the price and sets a minimum inflation (for both core and headline) in the economy. Now if inflation (for both core and headline) is pushed below this minimum, it has a cost in terms of destabilizing output. From equation (3.13), a trade-off also exists between stabilizing headline (or aggregate) inflation and the output gap as shown in Aoki (2001), but here the trade-offs will be higher as they get amplified by the presence of procurement.

To get an optimal instrument rule (an interest rate rule) under discretion, we first substitute targeting rules in the NKPC to obtain optimal values of the inflation rate, output gap and the terms of trade gap. We then substitute optimal values of the inflation rate, output gap and the terms of trade gap in the following DIS equation,

$$\begin{aligned}\widetilde{Y}^*_t &= E_t\left\{\widetilde{Y}^*_{t+1}\right\} - \frac{(1-\lambda_c)}{\sigma}\left[\widehat{R}_t - E_t\left\{\pi_{M,t+1}\right\} - \widehat{r}^*_t\right] + \\ &\quad \left(\frac{(1-\lambda_c)\delta}{\sigma} - \lambda_c\,(1-\delta)\right) E_t\left\{\Delta\widetilde{T}^*_{AM,t+1}\right\} \qquad (3.15)\end{aligned}$$

where

$$\widehat{r}_t^* = \widehat{r}_t^n + E_t\left\{\delta\Delta\widehat{T}_{AM,t+1}^*\right\} - \frac{\lambda_c\sigma(1-\delta)}{(1-\lambda_c)}E_t\left\{\Delta\widehat{T}_{AM,t+1}^* - \Delta\widehat{T}_{AM,t+1}^n\right\}$$
$$-\frac{\sigma}{(1-\lambda_c)}\left(\widehat{Y}_t^* - \widehat{Y}_t^n\right) + \frac{\sigma}{(1-\lambda_c)}E_t\left\{\widehat{Y}_{t+1}^* - \widehat{Y}_{t+1}^n\right\}.$$

is the efficient level of real interest rate. Note that the DIS equation (3.15) above is different from DIS equation (2.64) mentioned in Chapter 2, as the above equation in written in terms of efficient gaps.[32] The optimal interest rate rule under discretion is given by,

$$\widehat{R}_t^* = \widehat{r}_t^* + \frac{(1-X_4)}{X_3}E_t\left\{\sum_{j=0}^{\infty}\left(\frac{\beta}{X_3}\right)^j z_{2,t+1+j}^*\right\} + \frac{X_4}{X_3}E_t\left\{\sum_{j=0}^{\infty}\left(\frac{\beta}{X_3}\right)^j \Delta z_{2,t+j}^*\right\} - \sigma E_t\left\{\Delta z_{1,t+1}^*\right\} \tag{3.16}$$

where X_3, X_4 are combinations of parameters and $z_{2,t}^*$, $z_{1,t}^*$ are functions of shocks in the model as described in equation (3.6) and (3.11), respectively. Thus, an optimal interest rate rule under discretion is not just a function of current shocks but also expected future shocks affecting the economy. In a standard NK-DSGE model, without procurement, the optimal monetary policy rule under discretion suggests, $\widehat{R}_t^* = \widehat{r}_t^*$.[33] This follows form Proposition 1, such that when $c_p = 0$, $z_{2,t}^* = z_{1,t}^* = 0$, for all time periods t.

3.3.2 Optimal monetary policy under commitment

The optimal monetary policy under commitment is a policy where the monetary authority commits to an optimal policy plan at all possible dates and states of nature, current and

[32] Refer to the Technical Appendix B.3 for details.

[33] Refer to Chapter-5 of Gali (2008) and Woodford (2003) for the standard formulation of optimal interest rate rules.

future.[34] Formally, the problem can be written as,

$$\min_{\{\pi_{M,t},\, \widetilde{C}_t^*,\, \widetilde{T}_{AM,t}^*\}} \frac{1}{2}\lambda_{\pi M} E_0 \sum_{t=0}^{\infty} \beta^t \left[\pi_{M,t}^2 + \frac{\lambda_{\widetilde{C}}}{\lambda_{\pi M}} \left(\widetilde{C}_t^*\right)^2 + \frac{\lambda_{\widetilde{TAM}}}{\lambda_{\pi M}} \left(\widetilde{T}_{AM,t}^*\right)^2\right]$$

subject to

$$\pi_{M,t} = \beta E_t \left\{\pi_{M,t+1}\right\} + \lambda_M \left(\sigma + \psi \Theta_1\right) \widetilde{C}_t^* + \lambda_M \delta \widetilde{T}_{AM,t}^* + z_{2,t}^*$$

where the constraint is the NKPC as described in equation (3.10). Using the first order conditions from above optimization and aggregate output gap equation (3.5), we get the following *targeting rules*,

$$\widetilde{Y}_t^* = -\omega_1 \widehat{\widehat{P}}_{M,t} - (1-\lambda_c) z_{1,t}^* \tag{3.17}$$

$$\widetilde{T}_{AM,t}^* = -\omega_3 \widehat{\widehat{P}}_{M,t} \tag{3.18}$$

for $t = 0, 1, 2, ...$, where $\omega_3 = \frac{\lambda_{\pi M} \lambda_M \delta}{\lambda_{\widetilde{TAM}}}$ and $\widehat{\widehat{P}}_{M,t} = \widehat{P}_{M,t} - \widehat{P}_{M,-1}$. $\widehat{P}_{M,-1}$ is the price level in the manufacturing sector that prevails one period before the central bank chooses its optimal plan. The targeting rule under discretion in equation (3.12) has inflation as its target, but in the commitment case, equation (3.17), we get a price level target as an optimal targeting rule. In other words, given an initial price level in an economy, if a central bank commits to an inflation rate, it is also committing to a future path of the price level.[35]

Proposition 3 *In presence of procurement distortion, $c_p > 0$, there exists a trade off in stabilizing core inflation and the output gap i.e. no divine coincidence with optimal monetary policy under commitment. Divine coincidence only occurs when procurement distortion is absent, $c_p = 0$.*

Proof. The proof follows from the explanation in Proposition 2. Since $z_{1,t}^* \neq 0$, when $c_p > 0$, from the targeting rule in equation (3.17), the output gap and price level

[34] Refer to the Technical Appendix B.5 for detailed derivations.
[35] See Chapter-5 Gali (2008), for details.

gaps in manufacturing sector cannot be stabilized simultaneously. When a monetary policy completely stabilizes the output gap such that, $\widetilde{Y}_t^* = 0$, the minimum price gap in the manufacturing sector, $\widehat{\widehat{P}}_{M,t}$, that is attainable is $-\frac{(1-\lambda_c)}{\omega_1} z_{1,t}^*$. Similarly, when price gaps are completely stabilized, $\widehat{\widehat{P}}_{M,t} = 0$, the minimum possible output gap is, $\widetilde{Y}_t^* = -(1-\lambda_c) z_{1,t}^*$. Once we get the optimal path of the price gaps we get core inflation as $\pi_{M,t} = \widehat{\widehat{P}}_{M,t} - \widehat{\widehat{P}}_{M,t-1}$. Since price gaps are in a trade off with output gap stabilization, core inflation, which is a change in price gaps over time, is also in a trade off with output gap stabilization. When $c_p = 0$, $z_{1,t}^* = 0$ following Proposition 1. Thus, monetary policy can achieve $\widehat{P}_{M,t} = 0$ and $\widetilde{Y}_t^* = 0$ for $t = 0, 1, 2, ...$, with optimal monetary policy under commitment. Also, $\pi_{M,t} = 0$ and $\widetilde{Y}_t^* = 0$ for $t = 0, 1, 2, ...$exists and divine-coincidence occurs. ■

The following interest rate rule for policy under commitment is obtained by putting optimal values of the price level, output gap and the terms of trade gap in the DIS equation,

$$\begin{aligned} \widehat{R}_t^* &= \widehat{r}_t^* + \omega_5 (\varkappa_1 - 1) \widehat{\widehat{P}}_{M,t} + \frac{\omega_5}{\varkappa_2 \beta} E_t \sum_{k=0}^{\infty} \left(\frac{1}{\varkappa_2} \right)^k z_{2,t+1+k}^* \\ &\quad - \frac{\sigma}{(1-\lambda_c)} (1-\lambda_c) E_t \left\{ z_{1,t+1}^* - z_{1,t}^* \right\} \end{aligned} \quad (3.19)$$

$$\text{where, } \widehat{\widehat{P}}_{M,t} = \frac{1}{\varkappa_2 \beta} \sum_{j=0}^{t} \varkappa_1^j \sum_{k=0}^{\infty} \left(\frac{1}{\varkappa_2} \right)^k z_{2,t+k-j}^*$$

The optimal interest rate rule under commitment is a function of past, current and future shocks.

3.3.3 The efficient policy frontier (EPF)

In this section, we plot the trade-off in inflation and output stabilization associated with minimizing welfare losses, as discussed in the previous section.[36] An *efficient policy frontier* (EPF) is a loci of points, such that it is not possible to attain lower inflation variability (core-inflation, $\pi^2_{M,t}$, or headline inflation, π^2_t) without increasing variability of the output gap $\left(\widetilde{Y}_t^{*^2}\right)$ and vice versa. Thus, any policy rule that results in inflation-output variability above the frontier is not efficient. In other words, better outcomes are theoretically possible with a different rule. To produce an EPF we plot inflation-output variability values that minimize the welfare loss function for a range of values on the output gap weight. A lower weight on the output gap indicates strict inflation targeting and a higher weight reduces the importance of inflation targeting. Since we have a consumption gap in the welfare loss function, we vary the weight on consumption gap, $\lambda_{\widetilde{C}}$, as it would be proportional to the weight on the output gap.[37] The value of $\lambda_{\widetilde{C}}$, varies between $[0,\ 500]$. We graph the EPF for optimal monetary policy rule under discretion and optimal monetary policy rule under commitment in Figures 3-5 - 3-7.

[INSERT FIGURE 3-5]

Figure 3-5 shows an EPF for a trade-off between core-inflation and output gap stabilization, and between headline inflation and output gap stabilization (see Figure 3-5a and 3-5b, respectively) for optimal monetary policy under discretion.[38] It is clear that we cannot reduce the variability in inflation without increasing the variability in the output gap. Points A and P in Figure 3-5a and 3-5b respectively, correspond to optimal policy results when $\lambda_{\widetilde{C}} = 0$, i.e., when there is no weight on output gap stabilization. As a result we see a large variance in the output gap. The other extreme points C and R in Figure

[36] For this exercise we use the calibration listed in Table 2.2 of Chapter 2.

[37] We keep the weights on $\pi_{M,t}$ and $\widetilde{T}^*_{AM,t}$ constant at, $\lambda_{\pi m}$ and $\lambda_{\widetilde{Tam}}$, respectively. For details see, Chapter-6, Woodford (2003).

[38] We observe that a similar trade-off exists between stabilizing the terms of trade gap, $\widetilde{T}^*_{AM,t}$, and the output gap, $\widetilde{Y}^*$, but not between the terms of trade gap, $\widetilde{T}^*_{AM,t}$, and core-inflation, $\pi_{M,t}$.

3-5a and 3-5b respectively, correspond to optimal policy results when $\lambda_{\widetilde{C}}$ is sufficiently large. Points C and R correspond to the case of strict *core* inflation targeting and strict *headline* inflation targeting, respectively. For the present model economy, an optimal policy under discretion represents point B and Q in Figure 3-5a and 3-5b respectively. Variation in inflation (both core and headline) and variation in the output gap is positive at minimum welfare losses for varying values of $\lambda_{\widetilde{C}}$. The size of procurement determines the extent of the inflation-output trade-off here. Figure 3-6 below shows how the trade-off varies with the procurement level.

[INSERT FIGURE 3-6]

This figure plots the EPFs for values of c_p namely, 0.06, 0.08, 0.10, 0.12, with optimal monetary policy under discretion. As the value of c_p, rises, the EPF pushes out such that minimum variance of inflation and the output gap is higher now. The minimum welfare losses possible under discretion are also strictly higher for higher values of c_p.[39] This happens because an increase in c_p increases the gap between the efficient equilibrium and the flexible price equilibrium, thus the absolute value of $z^*_{1,t}$ increases (see equation (3.6)). This increases the trade-offs in targeting rule equations (3.12) and (3.13). An EPF does not exist for $c_p = 0$, i.e., no trade-off exists between core-inflation and output gap stabilization in the absence of procurement distortion. In other words, the minimum losses possible are zero in the absence of procurement. This follows from Proposition 2. This case of $c_p = 0$ is similar to Aoki (2001).

A trade-off between inflation and output stabilization also exists in the optimal policy under commitment as plotted in Figure 3-7.

[INSERT FIGURE 3-7]

Figure 3-7 compares the EPFs for the trade-off between core-inflation and output gap stabilization, and between headline inflation and output gap stabilization (in Figure 3-5a

[39]Note that, the EPF for the calibrated value of the model is with $c_p = 0.08$.

and 3-5b, respectively) for optimal monetary policy under discretion and commitment. The trade-off exists between core-inflation and output gap stabilization, only for $c_p > 0$, as for the case under commitment. This follows from Proposition 3. Trade-offs are higher under discretion than under commitment. For a given value of variation in inflation (both core and headline), the variation in the output gap under commitment is at least as high as variation in the output gap under discretion. Similarly, for a given value of variation in the output gap, variation in inflation (both core and headline) under commitment is at least as high as variation in inflation under discretion. In other words, an EPF for a discretionary policy has a higher slope than an EPF for a commitment policy for all arbitrary values of $\lambda_{\widetilde{C}}$ except when $\lambda_{\widetilde{C}} = 0$, in which case the two policies coincide. An optimal monetary policy rule under commitment gives lower minimum losses than an optimal monetary policy rule under discretion, because it avoids the stabilization bias present in a discretion rule. The discretionary policy attempts to stabilize the output gap in future periods and does not internalize the benefits of short term stabilization policy as the optimal policy under commitment suggests. This is well established in the literature.[40] Note that the minimum welfare losses possible are not zero but positive in the presence of procurement distortion both under the discretionary policy as well as commitment policy.

3.3.4 Implementable monetary policy rules

The optimal discretionary and commitment rule in equation (3.16) and (3.19), respectively, are theoretically the best monetary policy rules that minimize welfare losses. While these rules are desirable implementing them has the following disadvantages. First, these rules do not guarantee a unique equilibrium. The existence of a unique equilibrium depends on parameter values.[41] Second, they are not easy to implement. It is apparent from the optimal interest rate rules in equation (3.16) and (3.19) that they depend on

[40]See Gali (2008) and Woodford (2003) for further details.
[41]For the given calibration, a unique equilibrium does exist.

the current and future path of shocks which are not known to a policymaker precisely. These imprecisions can lead to large welfare losses. At best these optimal rules can be used as a benchmark for normative analysis. We therefore discuss some simple interest rate rules which are easy to implement and do a comparative analysis among them in this section.

Taylor (1999) discusses advantages of a class of simple rules over a class of optimal rules. For comparative analysis of monetary policy rules later in the chapter, we use a following simple Taylor rule, as described in Taylor (1993), with an added relative price/ terms of trade term,

$$R_t = (R_{t-1})^{\phi_R} (\pi_t)^{\phi_\pi} \left(\frac{Y_t}{Y_t^*}\right)^{\phi_{\widetilde{y}}} \left(\frac{T_{AM,t}}{T_{AM,t}^*}\right)^{\phi_{\widetilde{tam}}}.$$

Here $\phi_R > 0$ is interest rate smoothing parameter, $\phi_\pi > 0$, $\phi_{\widetilde{y}} > 0$ and $\phi_{\widetilde{tam}} > 0$ are weights on headline inflation, the output gap and the terms of trade gap, respectively.[42] It has been shown in Anand et al. (2015) that headline inflation targeting rules improves welfare outcomes vis-a-vis core-inflation targeting rules. Following this paper, we keep headline inflation as the measure of inflation rate here. We add terms of trade to a Taylor rule for two reasons. First, it is empirically observed that some countries consider relative prices among sectors while setting monetary policy (see Cuevas and Topak (2008)). Second, the derived welfare loss function, equation (3.4) , has variability in the terms of trade gap besides variability of the inflation term and the consumption gap. Thus, it appears natural to see how adding terms of trade gaps to the interest rate rule affects welfare outcomes. Cuevas and Topak (2008) estimate such a Taylor rule for South Africa and some other countries. They show that countries with high inflation and inflation expectations respond more aggressively to relative prices/ sectoral terms of trade. The

[42] We assume that the inflation target is zero.

log-linearized version of the above Taylor-rule is:[43]

$$\widehat{R}_t = \phi_r \widehat{R}_{t-1} + \phi_\pi \pi_t + \phi_{\widetilde{y}} \widetilde{Y}_t^* + \phi_{\widetilde{tam}} \widetilde{T}_{AM,t}^* \tag{3.20}$$

When $\phi_{\widetilde{tam}} = 0$, the above rule reduces to a standard simple Taylor rule,

$$\widehat{R}_t = \phi_r \widehat{R}_{t-1} + \phi_\pi \pi_t + \phi_{\widetilde{y}} \widetilde{Y}_t^* \tag{3.21}$$

The Taylor parameters, namely, interest rate smoothing parameter, ϕ_R, weights on inflation, ϕ_π, and the output gap, $\phi_{\widetilde{y}}$ are set using Anand et al. (2015) to 0.7, 2 and 0.5, respectively. The weight on the terms of trade gap, $\phi_{\widetilde{tam}}$, in the Taylor rule is set to 0.864 as estimated in Cuevas and Topak (2008).[44]

3.4 Comparative analysis

We calibrate the model and compare five monetary policy rules namely, an optimal interest rate rule under discretion, an optimal interest rate rule under commitment, a simple Taylor rule *without* terms of trade gaps, a simple Taylor rule *with* terms of trade gaps, as shown in equation (3.16) , (3.19) , (3.21) and (3.20) , respectively, and an optimal simple rule. An *optimal simple rule* (OSR) is a rule like equation (3.20) where the value of coefficients, ϕ_R, ϕ_π, $\phi_{\widetilde{y}}$ and $\phi_{\widetilde{tam}}$, are chosen such that the welfare loss function is minimized.[45] We do these comparisons for a positive procurement shock, $\widehat{Y}_{PG,t}$, and a negative productivity shock, $\widehat{A}_{G,t}$ to the grain sector.

[43]Note that gaps are from efficient levels.

[44]Cuevas and Topak (2008) does the estimation for the South African economy. To the best of our ability, we could not find a paper on the Indian economy that estimates the Taylor rules with a inter-sectoral terms of trade.

[45]To get the optimal simple rule, we do the numerical optimization to minimize welfare loss function in Dynare. To do this we initialize the value of parameters with the calibrated values, i.e. $\phi_R = 0.7$, $\phi_\pi = 2$, $\phi_{\widetilde{y}} = 0.5$ and $\phi_{\widetilde{tam}} = 0.864$.

3.4.1 Procurement shock

We analyze the response of the economy to a one period positive procurement shock in the grain sector (s.d. 0.66) when the central bank follows five different monetary policy rules as discussed above. Table 3.1 shows welfare losses, values of Taylor rule coefficients, and standard deviation of the nominal rate of interest with different rules.

Rule	Welfare losses#	ϕ_R	ϕ_π	$\phi_{\widetilde{y}}$	$\phi_{\widetilde{tam}}$	s.d.(R)
Simple Taylor rule						
without ToT*	0.3914	0.7	2	0.5	0	0.0110
with ToT	0.3565	0.7	2	0.5	0.864	0.0117
Optimal monetary policy						
Discretion	0.1196	n.a.	n.a.	n.a.	n.a.	0.0055
Commitment	0.0928	n.a.	n.a.	n.a.	n.a.	0.0127
Optimal simple rule (OSR)ˆ	0.3090	0.576	2.029	0.741	0.601	0.0116

n.a. is 'not applicable' here as the discretion and commitment rules are endogenous

Percentage deviation from the steady state

* ToT refers to terms of trade gap

ˆOSR also belongs to a class of implementable rules

Table 3.1: Monetary policy rules for a positive procurement shock

A simple Taylor rule *without* terms of trade gap gives the highest welfare losses. The losses reduce by 9 per cent when the terms of trade gap is added to the simple Taylor rule and by 21 per cent with an optimal simple rule.[46] The optimal weight in front of $\widetilde{T}_{AM,t}$ in the optimal simple rule is positive and takes a value of 0.601. This means that sectoral terms of trade/ relative price gaps in the simple Taylor rule does improve welfare outcomes. Among the optimal monetary policy rules, a commitment rule gives the lowest welfare losses, followed by a discretion rule and then an optimal simple rule.

[46] Here optimal simple rule is the optimized simple Taylor rule with terms of trade gap which minimizes the welfare loss function.

Since an optimal simple rule gives the lowest welfare losses, it is best among the class of implementable rules considered here.

IRFs for a positive procurement shock

Figure 3-8 compares the IRFs for optimal monetary policy rules namely, discretion, commitment and the optimal simple rule for a one period positive procurement shock.

[INSERT FIGURE 3-8]

On impact the response of the output gap and consumption gap is smallest under commitment rule compared to discretion rule or the optimal simple rule. With a commitment rule, the response of the nominal rate of interest is negative on impact, which is in contrast to the other two policy responses. Due to this, consumption falls less and aggregate output increases further. Inflation (both core and aggregate) is less persistent under commitment as the price level (both core sector and aggregate) comes back to its initial level after four quarters. On the contrary, price levels (both core sector and aggregate) under discretion converges to a higher level permanently. The optimal simple rule performs very well for most nominal variables like inflation (both aggregate and headline), price levels and terms of trade. In fact, with OSR the price level converges close to its initial value in long run, similar to a commitment rule. On impact an OSR contracts an economy more than the other two optimal rules, but in the long run it performs very close to the commitment policy. Figure 3-9 compares IRFs for implementable simple rules, namely, a simple Taylor rule, simple Taylor rules with terms of trade gaps and an OSR for a one period positive procurement shock.

[INSERT FIGURE 3-9]

On impact, the simple Taylor rule response to the shock is insufficient to stabilize nominal variables like inflation (both core and headline inflation), terms of trade and price levels (which remain permanent high). On the other hand, the response of a simple

Taylor rule with a terms of trade gap is too aggressive, which deflates the economy such that the economy converges to a price level lower than its initial level. The optimal simple rule performs the best among all three implementable rules considered here in stabilizing inflation (both core and output) and price level as discussed earlier. Since a trade-off exists between inflation and output stabilization, we see that real variables respond the least for simple a Taylor rule. As summarized in Table 3.1, the welfare losses are 21 per cent less with an optimal simple rule as compared to a simple Taylor rule and hence it is the best rule among considered implementable rules. The optimal simple rules with terms of trade gaps perform better than the simple Taylor rules because they ensure that monetary policy reacts to shocks that lead to significant changes in intersectoral relative prices. Higher and persistent changes in the intersectoral relative prices leads to inefficient outcomes.

3.4.2 Productivity shock

We now analyze the response of the economy to a one period negative productivity shock in the grain sector (s.d. 0.03) when the central bank follows five different monetary policy rules as discussed above. We do this in two parts. In the first part we do away with the procurement distortion and put $c_p = 0$; in the second part we analyze the policies in the presence of procurement with $c_p = 0.08$.

Without procurement distortion

We put $c_p = 0$ in this section, such that the results can be compared to any standard multi-sector model with a negative productivity shock. Table 3.2 shows welfare losses, values of Taylor rule coefficients and standard deviation of the nominal rate of interest of the shock with different rules.[47]

[47] Any values of losses less than 10^{-30} are put a zero.

Rule	Welfare losses^	ϕ_R	ϕ_π	$\phi_{\widetilde{y}}$	$\phi_{\widetilde{tam}}$	s.d.(R_t)
Simple Taylor rule						
without ToT*	0.0115	0.7	2	0.5	0	0.0120
with ToT	0.0076	0.7	2	0.5	0.864	0.0109
Optimal monetary policy						
Discretion	0.0000	n.a.	n.a.	n.a.	n.a.	0.0040
Commitment	0	n.a.	n.a.	n.a.	n.a.	0.0040
Optimal simple rule	0.0039	1.240	1.792	0.568	1.005	0.0085

n.a. is 'not applicable' here as the discretion and commitment rules are endogenous

Percentage deviation from the steady state

* ToT refers to terms of trade gap

^OSR also belongs to a class of implementable rules

Table 3.2: Monetary policy rules for a negative productivity shock with no procurement

A simple Taylor rule without a terms of trade gap gives the highest welfare losses. The losses reduce by 33 per cent when a terms of trade gap is added to the simple Taylor rule and by 66 per cent with the optimal simple rule. The optimal weight in front of $\widetilde{T}_{AM,t}$ in the optimal simple rule is positive and takes a value of 1.005, which is higher than our calibrated value of 0.864. This means that sectoral terms of trade/ relative price gaps in the simple Taylor rule improves the welfare outcome. Among the optimal monetary policy rules, the discretion and commitment rules are the same as both policies completely stabilize core-inflation, output gap and the terms of trade gap, i.e. $\pi_{M,t} = \widetilde{Y}_t^* = \widetilde{C}_t^* = \widetilde{T}_{AM,t}^* = 0$. Note that there are no trade-offs between stabilizing core-inflation and output gap when, $c_p = 0$. This case resembles Aoki (2001). An optimal simple rule although performs worst among the optimal rules but is best among the considered implementable rules.

IRFs for a negative productivity shock without procurement distortion

Figure 3-10 compares the IRFs for optimal monetary policy rules namely, discretion, commitment and the optimal simple rule for a one period negative productivity shock.

[INSERT FIGURE 3-10]

The IRFs show that the discretion and commitment rules give the same response for all the variables in the economy, as explained above. Core-inflation, the output gap and terms of trade gap are all zero under discretion and commitment policy rules, as there is no trade-off. The price level returns to its original levels under these two policies. The optimal simple rule on the other hand performs well for aggregate inflation and the aggregate price level, but poorly for core sector inflation and the price level. On impact an optimal simple rule also contracts the economy more than the other two optimal rules.

Figure 3-11 compares the IRFs for implementable simple rules namely, a simple Taylor rule, a simple Taylor rules with a terms of trade gaps and an optimal simple rule for one period negative productivity shock.

[INSERT FIGURE 3-11]

The response of most of the variables seem similar for all three rules on impact except for core-inflation and the price level (both aggregate as well as core-sector) where the optimal simple rule performs better. Under an optimal simple rule, core inflation is strictly less for all periods and prices deviate less from the steady state in the long run. Between the second and fourth quarter, the output gap, consumption gap and terms of trade gap are more stable with an OSR. Overall the optimal simple rule performs the best by reducing welfare losses upto 66 per cent as compared to a simple Taylor rule.

With procurement distortion

We put $c_p = 0.08$, as calibrated for the Indian economy, in this section. Table 3.3 shows welfare losses, values of Taylor rule coefficients and standard deviation of the nominal rate of interest of the shock for different rules.

Rule	Welfare lossesˆ	ϕ_R	ϕ_π	$\phi_{\widetilde{y}}$	$\phi_{\widetilde{tam}}$	s.d.(R)
Simple Taylor rule						
without ToT*	0.0128	0.7	2	0.5	0	0.0125
with ToT	0.0081	0.7	2	0.5	0.864	0.0114
Optimal monetary policy						
Discretion	0.0016	n.a.	n.a.	n.a.	n.a.	0.0042
Commitment	0.0001	n.a.	n.a.	n.a.	n.a.	0.0036
Optimal simple rule	0.0049	1.153	1.8	0.548	1.001	0.0092

n.a. is 'not applicable' here as the discretion and commitment rules are endogenous

Percentage deviation from the steady state

* ToT refers to terms of trade gap

ˆOSR also belongs to a class of implementable rules

Table 3.3: Monetary policy rules for a negative productivity shock with procurement

As expected, welfare losses under *all* five rules in Table 3.3 are higher in the presence of a procurement distortion as compared to Table 3.2. A simple Taylor rule without a terms of trade gap gives the highest welfare losses here too. The welfare losses reduce by 36 per cent when terms of trade gap is added to the simple Taylor rule and by 62 per cent with the optimal simple rule. The optimal weight in front of $\widetilde{T}_{AM,t}$ in the optimal simple rule is positive and takes a value of 1.001, which is higher than the calibrated value of 0.864. This means that the sectoral terms of trade/ relative price gaps in the simple Taylor rule improves welfare outcomes. With procurement, the welfare losses are positive under discretion and commitment rules, as trade-off between inflation and output gap stabilization exists and welfare minimizing values of $\pi_{M,t}, \widetilde{Y}_t^*$, $\widetilde{C}_t^*$, $\widetilde{T}_{AM,t}^*$ are not zero. Among the optimal monetary policy rules, the commitment rule gives the lowest welfare losses, followed by the discretionary policy and then the optimal simple rule (OSR).

IRFs for a negative productivity shock with procurement distortion

Figure 3-12 compares the IRFs for optimal monetary policy rules namely, discretion, commitment and optimal simple rule for a one period negative productivity shock.

[INSERT FIGURE 3-12]

The IRFs show that with procurement distortion, discretion and commitment rules do not give the same response for all the variables in the economy, specially the price levels (both aggregate and core-sector). Moreover, core-inflation, the output gap and terms of trade gap are not zero under discretion and commitment policy rules, as there exists a trade-off. Between the second to fourth quarter these variables become more stable under a commitment policy. The optimal simple rule on the other hand performs well for aggregate inflation and the aggregate price level, but poorly for core sector inflation and the price level. On impact, the optimal simple rule contracts the economy more than the other two optimal rules.

Figure 3-13 compares the IRFs for implementable simple rules namely, a simple Taylor rule, simple Taylor rules with a terms of trade gaps and an optimal simple rule for a one period negative productivity shock.

[INSERT FIGURE 3-13]

The graphs in Figure 3-13 are not qualitatively different from the graphs in Figure 3-11, although the presence of procurement affects the values of the variables. The output gap and consumption gap are higher in the presence of procurement for all time periods.[48] The response of most of the variables seems similar on impact except, core-inflation and price levels (both aggregate as well as core-sector) where optimal simple rule performs better. Under the optimal simple rule core inflation is strictly less for all periods and prices deviate less from the steady state values in the long run. Between the second

[48]For other variables the effect is small and is not visible on the graphs.

and fourth quarter, the output gap, consumption gap and the terms of trade gap are more stable. Overall an optimal simple rule performs the best among the implementable interest rate rules considered and reduces welfare losses upto 62 per cent as compared to a simple Taylor rule.

The ranking of monetary policy rules based on the welfare losses and the IRFs remains the same across all three cases of procurement shock, productivity shock (without procurement) and productivity shock (with procurement). Although with a productivity shock (without procurement), the commitment and the discretion outcomes coincide. Optimal simple rules with the terms of trade gaps perform best among the subset of implementable rules considered for the comparative analysis. This is not to say that the optimal simple rules are the best among the class of all possible implementable rules.

3.5 Conclusion

Our paper contributes to a growing literature on monetary policy for India and other EMDEs. Most of the literature in monetary policy setting for developing countries focusses on the optimal inflation index that should be targeted to bring an economy close to the flexible-price equilibrium. Real disturbances which can be a source of inefficient shocks to EMDEs and possibly generate trade-offs between inflation and output gap stabilization for central banks, have not been studied much in the literature. This chapter attempts to incorporate real structural challenges in EMEs within a modelling framework of monetary policy design and derive optimal monetary policy rules for more effective policy implementation. In particular, we identify market price support present in the agriculture sector of EMDEs as a real disturbance leading to policy trade-offs. In other words, a government induced procurement policy in the Indian economy is a source of *inefficient* shocks. We derive the welfare loss function of central banks and characterize optimal monetary policy under discretion and commitment. We show that the presence of procurement induces trade-offs between core-inflation and output gap stabilization, and between headline inflation and output gap stabilization under both a discretion and commitment rule. This result is a departure from the existing popular view point that strict core-inflation targeting is the optimal monetary policy for developing countries. This implies that central banks in developing countries need more caution while setting their monetary policy, as the inefficiencies in the real sector of their economy can modify standard results and alter the optimal policy response. We find that, among the class of monetary policy rules considered for comparison, a commitment rule is the best rule with the least welfare losses. Among the implementable rules, an optimal simple rule, with terms of trade gap as one of the target variables (besides aggregate inflation and the output gap), reduces welfare losses significantly. As compared to a simple Taylor rule *without* terms of trade gaps, an optimal simple rule *with* terms of trade gap reduces welfare losses by 21 per cent and 62 per cent for a positive procurement shock and a negative productivity shock, respectively. Thus, a simple interest rate rule with terms of trade/ relative price gaps can be used by central banks in EMDEs, featured with large distorted agriculture sector, to improve welfare outcomes.

Figures

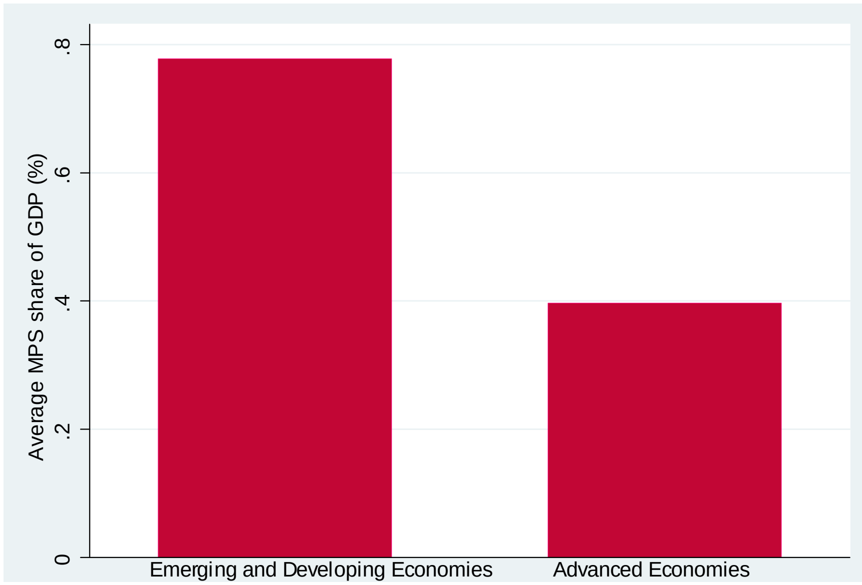

Figure 3-2: Agricultural Market Price Support as a share of GDP between 2011-15

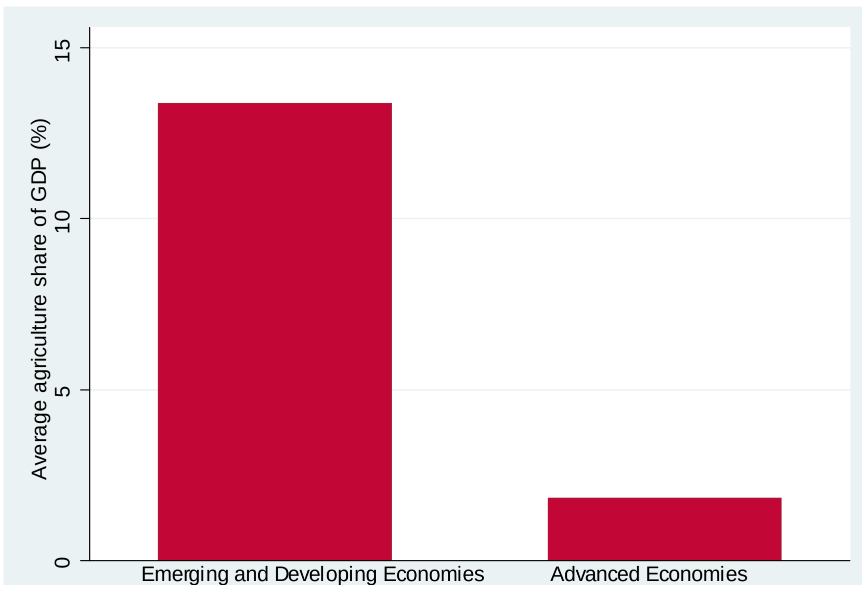

Figure 3-3: Value of agriculture sector as a share of GDP between 2011-15

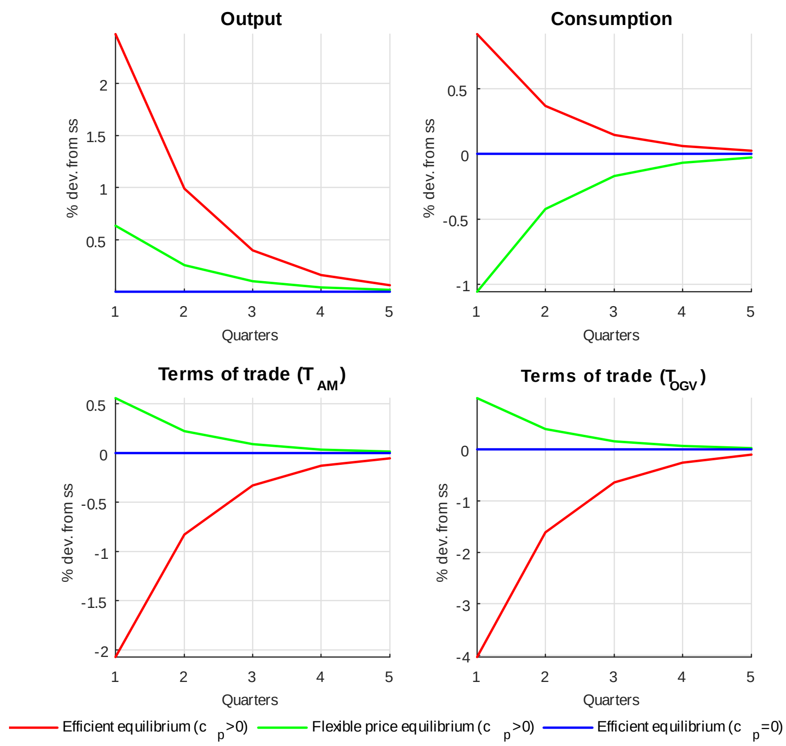

Figure 3-4: Comparing efficient and flexible price equilibrium

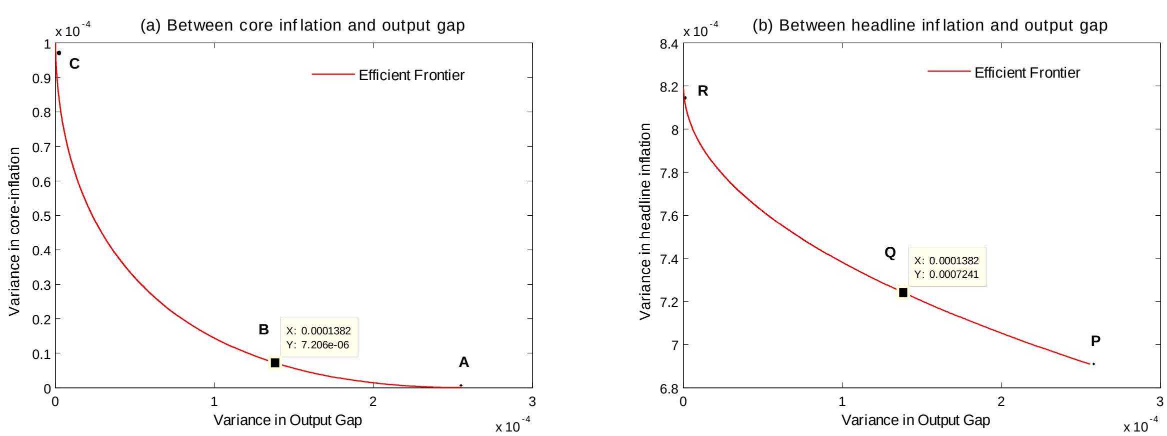

Figure 3-5: Trade-off between inflation and output stabilization

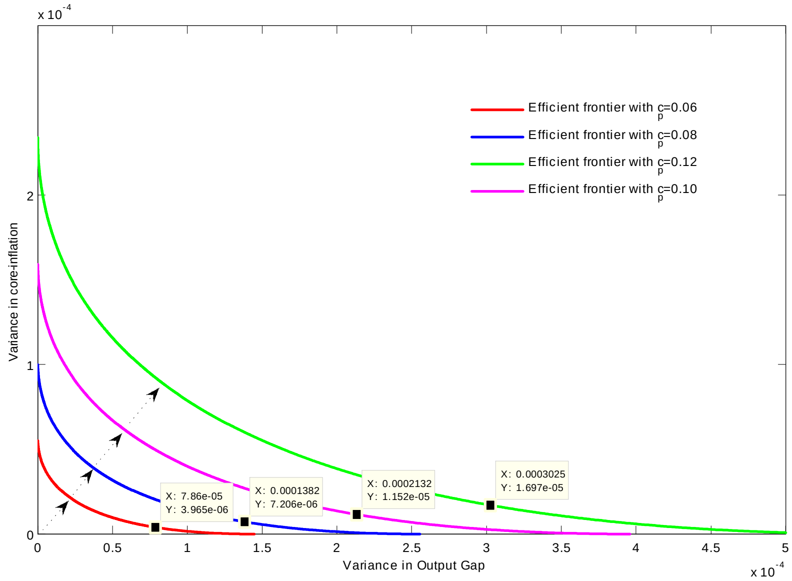

Figure 3-6: Trade-offs and varying procurement levels

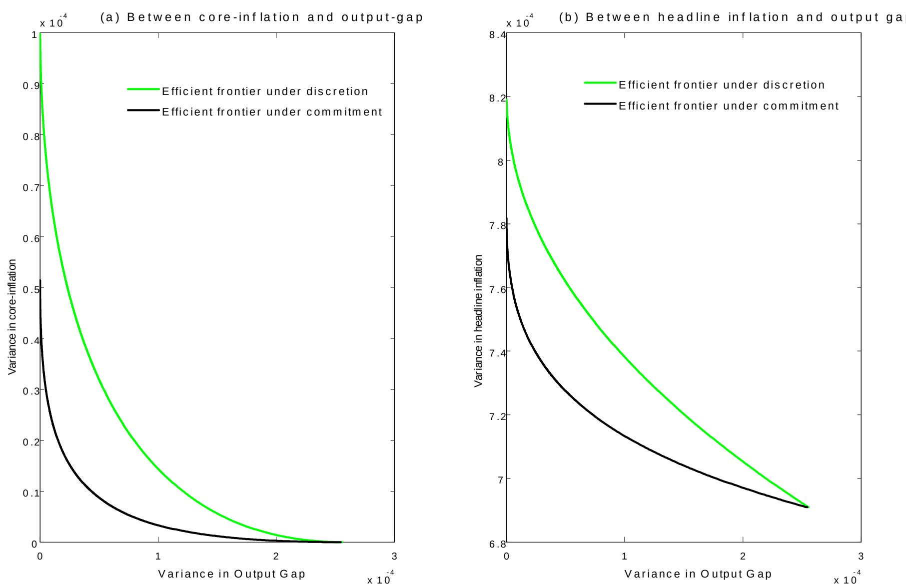

Figure 3-7: Trade-offs: Discretion vs. Commitment

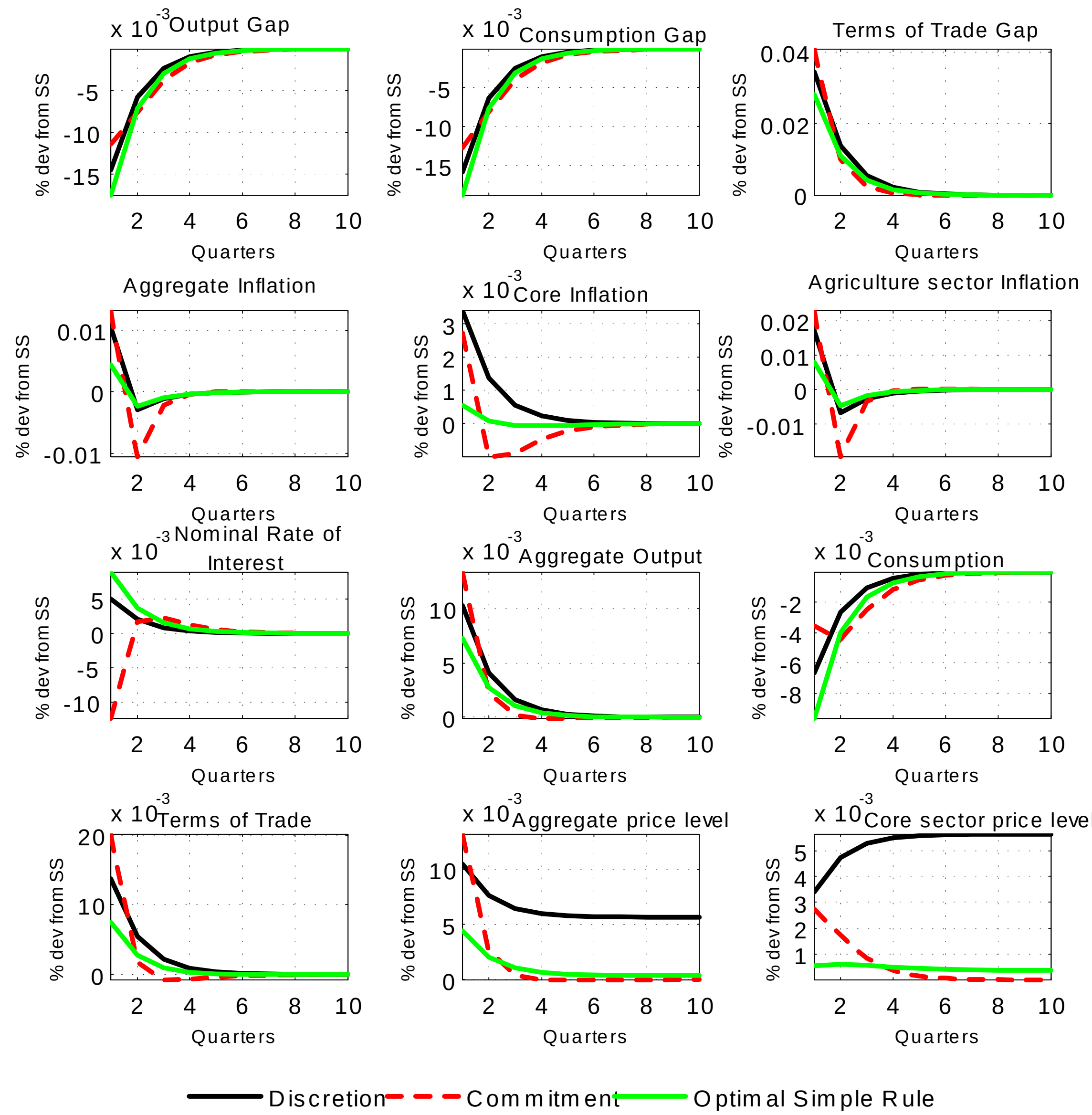

Figure 3-8: IRFs comparing optimal monetary policies for a procurement shock

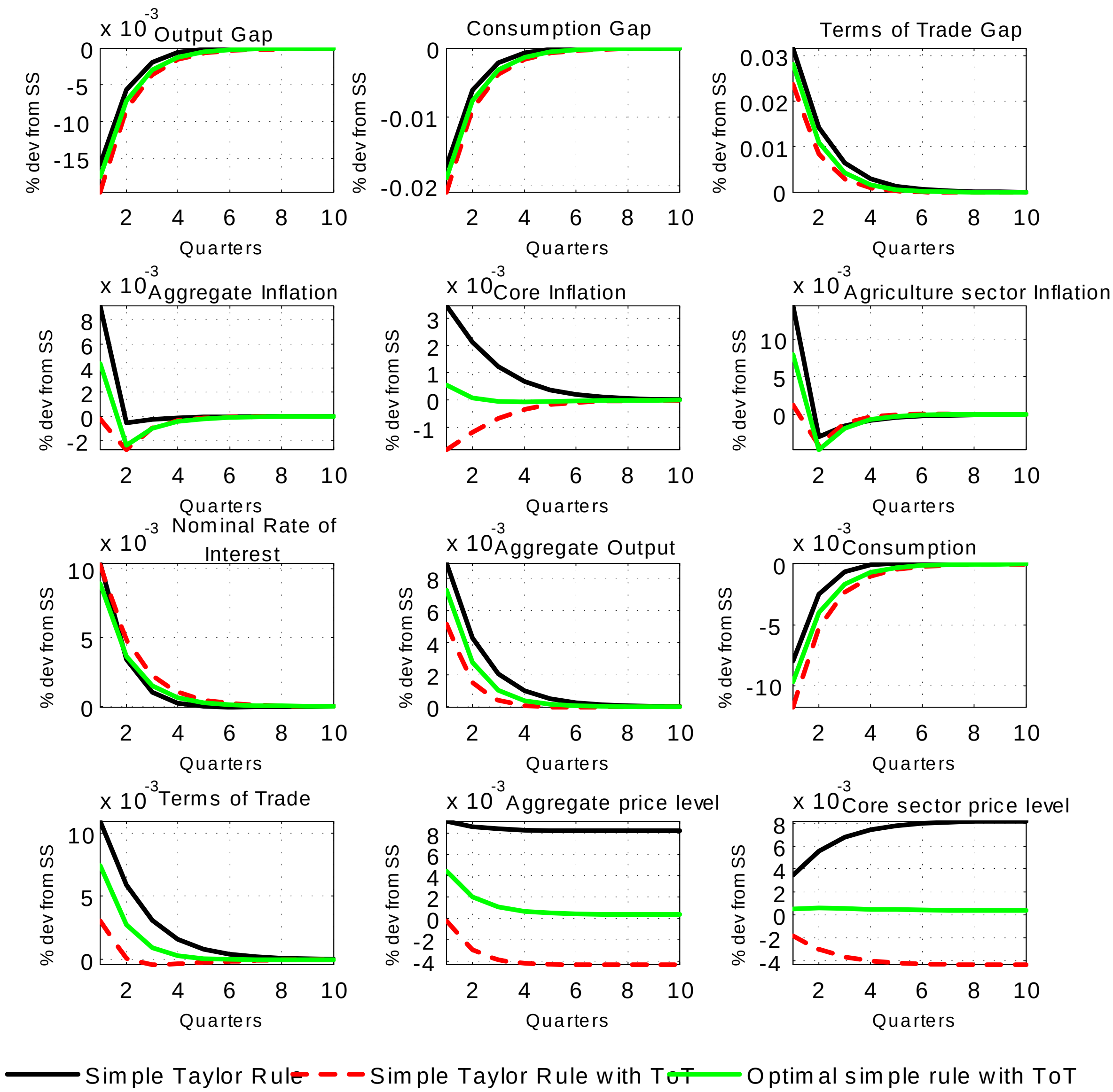

Figure 3-9: IRFs comparing an optimal simple rule and simple modified Taylor rules for a procurement shock

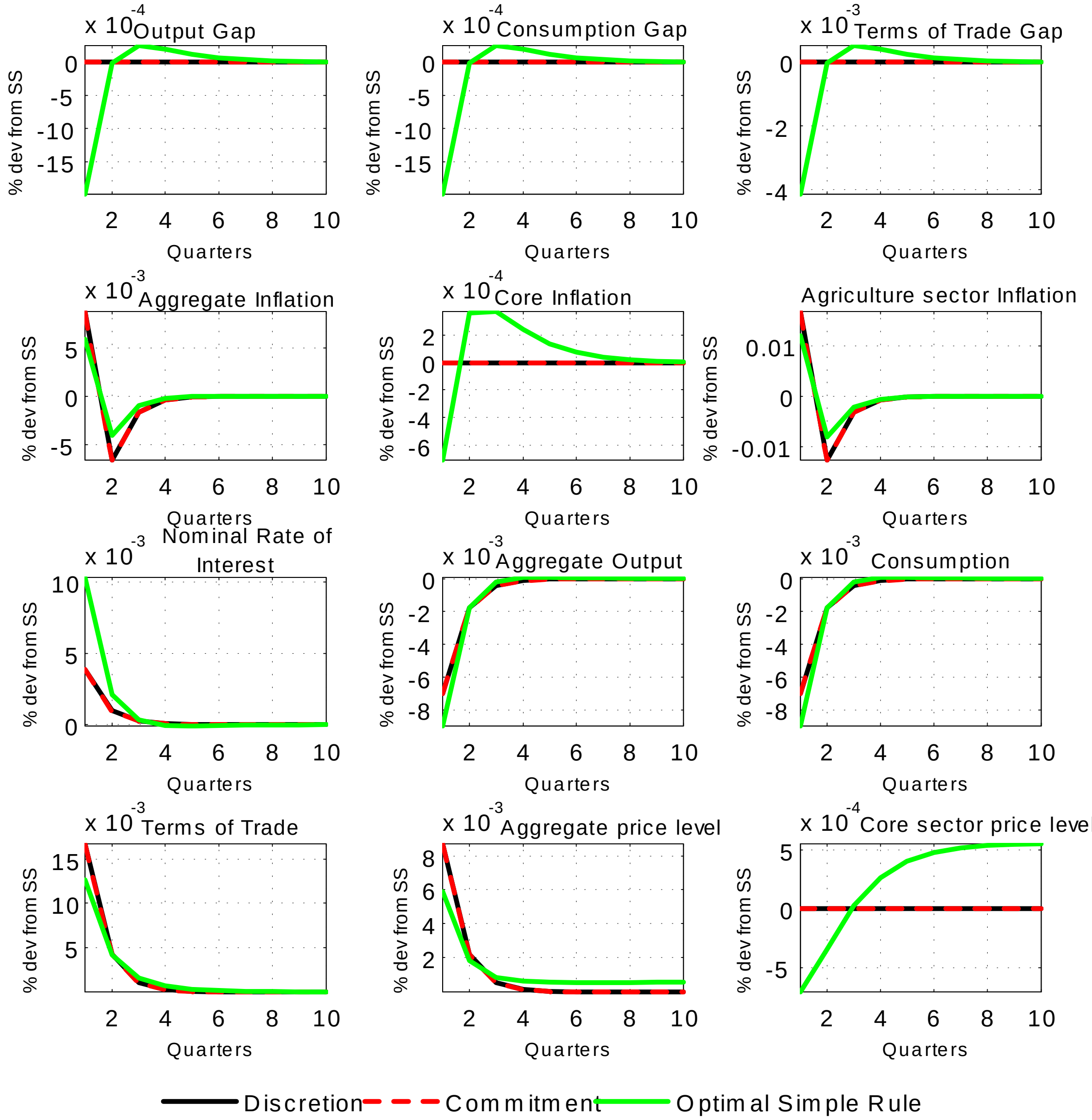

Figure 3-10: IRFs comparing optimal monetary policies for a productivity shock without procurement distortion

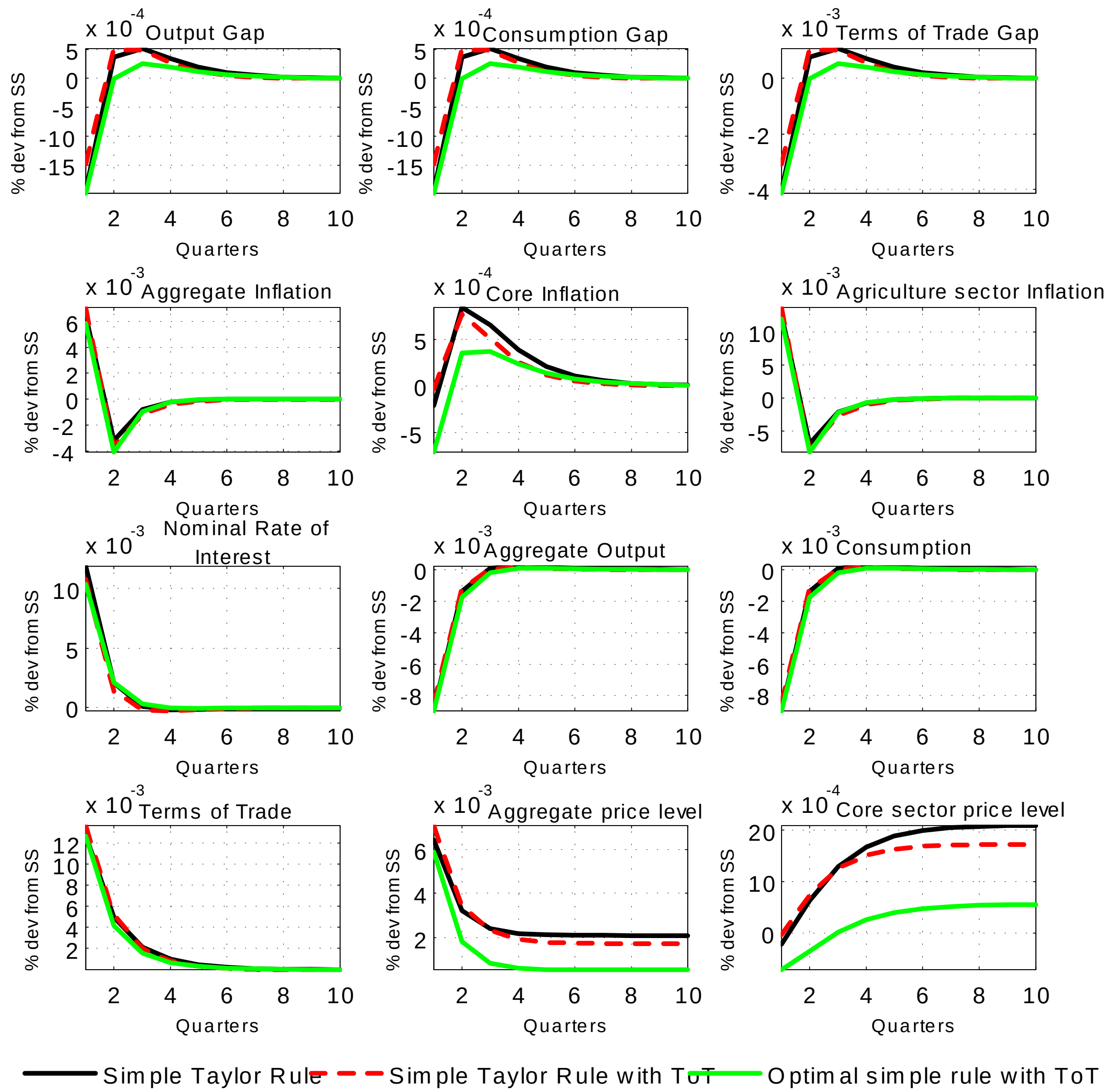

Figure 3-11: IRFs comparing an optimal simple rule and simple modified Taylor rules for a productivity shock without procurement distortion

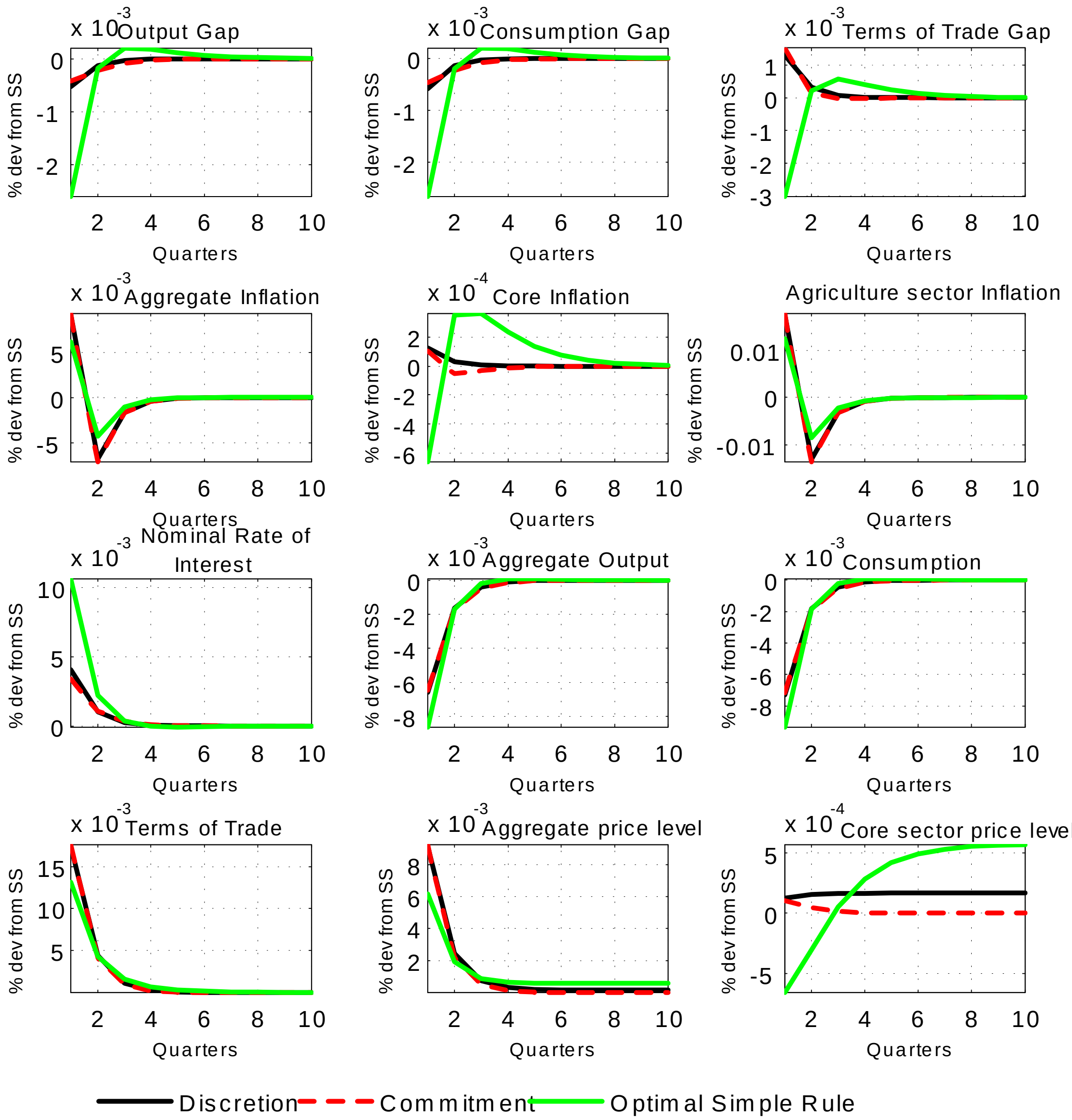

Figure 3-12: IRFs comparing optimal monetary policies for productivity shock with procurement distortion

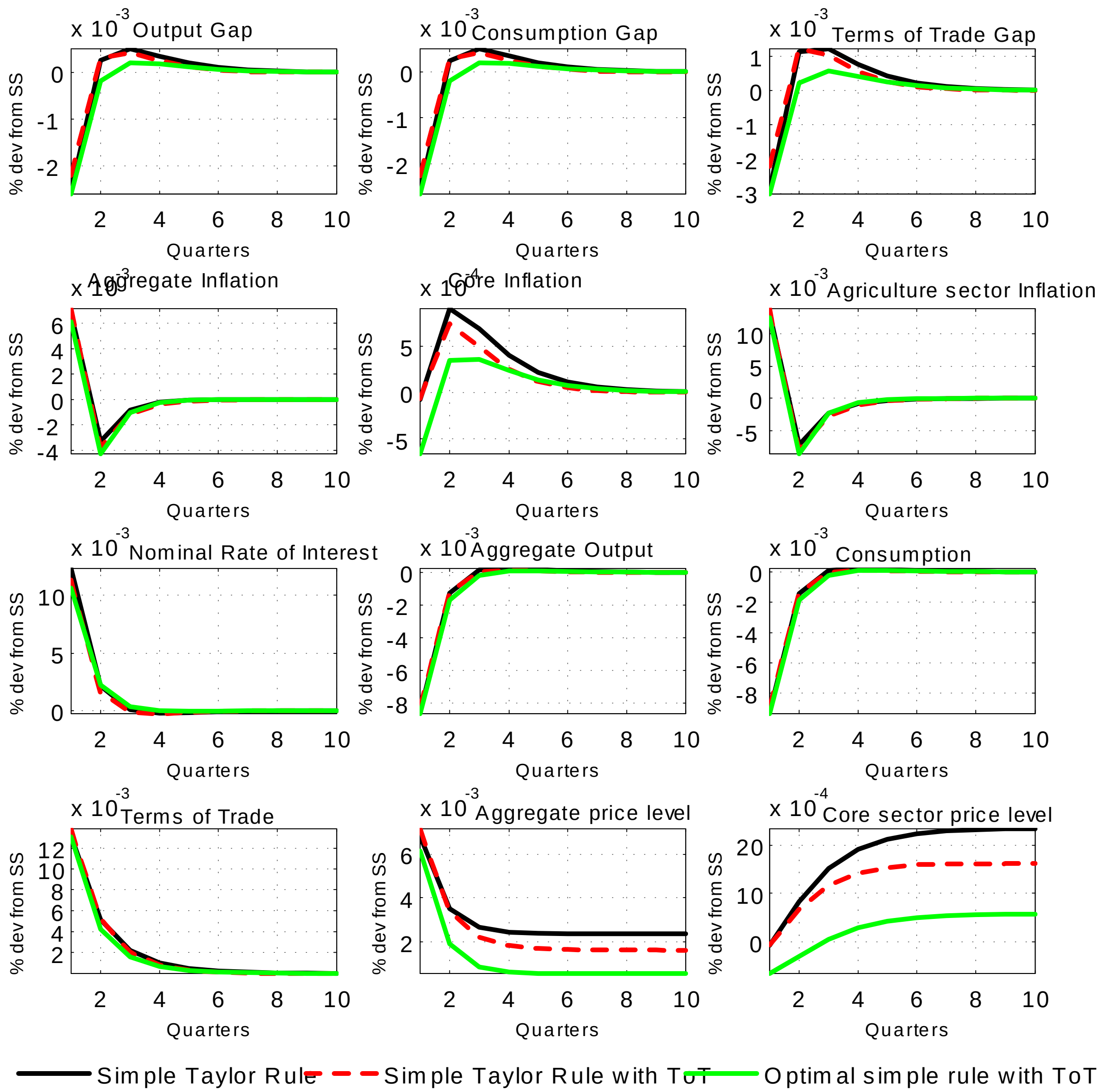

Figure 3-13: IRFs comparing an optimal simple rule and simple modified Taylor rules for a productivity shock with procurement distortion

Chapter 4

Uncertainty shocks and monetary policy rules in a small open economy

4.1 Introduction

There has been a surge in the macroeconomics literature on aggregate uncertainty post global financial crisis (GFC) of 2008-2009. The role of uncertainty shocks in slowing down the real economy and driving business cycles is getting well recognized in the literature. Using a reduced form VAR, Bloom (2009) estimates that global uncertainty shocks reduce U.S. industrial production by 1 per cent. Gourio et al. (2013) show a similar result for G7 countries. Bloom et al. (2018) show that uncertainty rises sharply during recessions and it reduces GDP by 2.5 per cent. Basu and Bundick (2017), using a new-Keynesian DSGE model, show that demand-determined output is the key mechanism for generating comovements observed in the data as a response to uncertainty fluctuations in US. Ravn and Sterk (2017) exposits the role of job uncertainty in amplifying adverse effect of GFC, using a model featuring labour market with matching frictions and inflexible wages.

While the literature on the impact of uncertainty shocks on emerging market economies macroeconomic outcomes is less developed, Fernández-Villaverde et al. (2011) show adverse real effects of an increase in real interest rate volatility (uncertainty in real interest rates) on output, consumption and investment. Cespedes and Swallow (2013) argue that global uncertainty shocks not only impact consumption and investment demand in advance economies (AEs) but also in emerging market economies.(EMEs). Their estimation shows that the impact of such shocks on EMEs is much more severe than AEs. Moreover emerging markets take much longer to recover due to credit constraints present in these economies. Chatterjee (2018) discusses the role of trade openness in explaining a disproportionately larger real effects of uncertainty shocks on EMEs compared to AEs, especially during a recessionary period.[1] To the best of our knowledge, the role of monetary policy in offsetting the adverse effects of global uncertainty shock in an EME and its link with the exchange rates is not explored in the literature. This chapter addresses this gap in the literature.

We examine the role of exchange rates and monetary policy rules in transmitting the effect of uncertainty shocks in a small open economy (EME). We observe that exchange rate movements are significant in EMEs vis-a-vis AEs, when global uncertainty rises. To be specific, the data distinctly shows that exchange rates, both nominal as well real, depreciate strongly during periods of high global uncertainty. This happens because capital moves out of EMEs as an immediate response to higher global uncertainty. Typically, when global risks are high investors move their risky asset portfolio into safer assets like US treasury bill and that's why EMEs experience a net portfolio outflow. This is consistent with the flight-to-safety hypothesis. Fratzscher (2012) finds strong empirical evidence showing that during the time of global financial crises when global risks (same as high global uncertainty) were high, emerging markets economies showed a significant net portfolio outflow. They also argue that global risks have been a key 'push factor' driving capital flows from EMEs.[2] A depreciating currency in an EME does not lead to

[1]In the trade literature, Magrini et al. (2018) also show that there are *ex-ante* risks due to trade exposure in Vietnam and these risks affect consumption growth. An *ex-ante* shock in the trade literature is closely associated with an uncertainty shock in the macroeconomics literature.

[2]Fratzscher (2012) also argues that country specific features including structural issues only affect the cross-country heterogeneity effects of common global shocks emanating from advanced economies. In other words, country specific features have been important determinants of 'pull factors' as a driver

an expansion of output, due to expenditure switching via trade channel, because increasing global uncertainty contracts world output too. Instead, the depreciating currency is contractionary here. This follows from the existing literature which has emphasized on the contractionary effect of a depreciating currency (see Agenor and Montiel (1999), Cook (2004) and Korinek (2018)).[3]

Further, due to a currency depreciation, domestic consumer prices increase due to an increase in the import prices in EMEs. As a response to increasing inflationary expectations, the central bank in EMEs increases the nominal interest rate.[4] Other possible reasons for increasing interest rates could be to put a check on the outflow of capital. Our stylized facts show that emerging markets grapple with a fall in private consumption and investment during episodes of increasing uncertainty, as shown in the recent literature described above. An increase in the nominal interest rate can further destabilize a contracting small open economy by reinforcing the adverse effect of uncertainty shocks. A monetary policy (implemented using Taylor type interest rate rules) is thus faced with a strong trade-offs in inflation and output stabilization.

Benigno et al. (2012) explore a link between uncertainty and exchange rates and show that the time variations in uncertainty is an important source of fluctuation in exchange rates. They also argue that when an uncertainty shock hits an economy, fluctuations in exchange rates are guided by a *hedging motive* and uncovered interest rate parity (UIP) does not hold, generating time varying risk premiums.[5] As shown in the left chart

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of capital flows.

[3]This happens because most of the external debt held by firms in emerging market economies is denominated in dominant currencies such as the US dollar. A depreciation (both nominal and real) of the currency would worsens the balance sheets of firms. With worsening balance sheets, foreign investors pull out their funds and firms hit a borrowing/ credit constraint. This can further make things worse if the currency depreciates further with capital moving out of the country. This point has also been emphasized in Cespedes and Swallow (2013) to explain a longer recovery time period for a fall in investment in emerging markets when hit with a global uncertainty shock.

[4]All the countries considered for the empirical analysis are inflation targeters and monetary policy follows an interest rate rule as an instrument to stabilize the economy. The results are based on using short-term interest rates as a proxy to policy rates.

[5]When an uncertainty shock hits the economy, capital looks out for a safer currency which leads to fluctuations in the exchange rates. See Menkhoff et al. (2012) for the link between deviation from the UIP and time varying risk premiums. Backus et al. (2010) have also shown that Taylor rules are

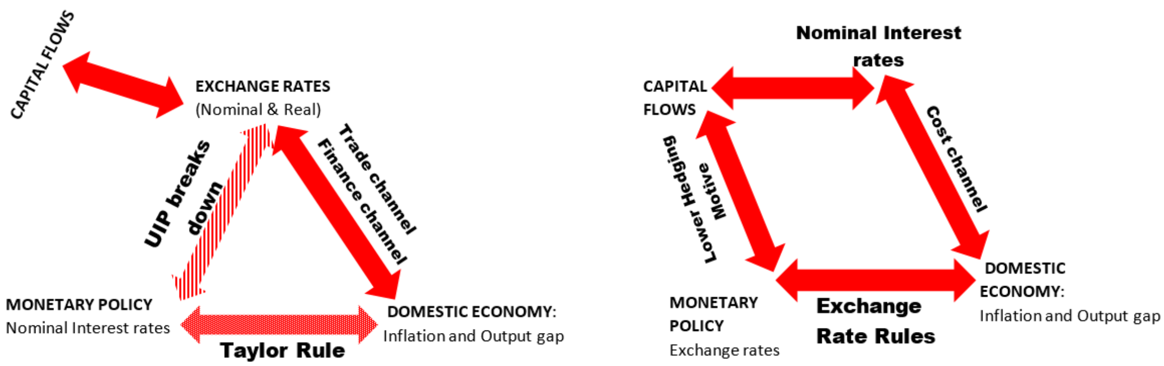

Figure 4-1: In presense of global uncertainty shock (a) Monetary policy using nominal interest rates as instrument (left); (b) Monetary policy using nominal exchange rates as instrument (right)

of Figure 4-1 below, when an economy deviates from UIP, the link between nominal interest rates (monetary policy instrument) and the nominal exchange rate breaks down. Thus any attempt to use an interest rate rule to stabilize the economy through the nominal exchange rate is unsuccessful.[6] To summarize, a depreciating domestic currency in EMEs aggravates the contractionary real effects of an increase in global uncertainty and leads to increase in inflation. Thus, in a small open economy (EME), stabilization of exchange rates is imperative to offset the adverse effects of increasing global uncertainty and interest rate rules fail to do so.

Finally, we build a small open economy new-Keynesian DSGE model with an uncertainty shock to world demand and examine the response of real macroeconomic variables under a variety of monetary policy rules. The purpose of this exercise is to look for a monetary policy rule which minimizes the welfare losses since interest rate rules are ineffective. Singh and Subramanian (2008) have shown that an essential feature that determines the optimal choice of the monetary policy instrument is the nature of shocks affecting the economy. Following this we consider the response of the economy under an

associated with high risk premiums.

[6]This point is also emphasized in Heiperzt et al. (2017).

alternate monetary policy instrument.

A most obvious alternate policy to be considered here is a fixed exchange rate regime. Cook (2004) has argued that a fixed exchange rate regime (PEG) offers greater stability than an interest rate rule (or flexible exchange rate regime) when currency depreciation destabilizes the business cycle. We show that a fixed exchange rate regime does only slightly better than an interest rate rule, in terms of welfare losses, as it brings high variability to other nominal variables in the economy like consumer price inflation (CPI), which adjusts more. Although fixed exchange rate does bring a greater stability to macroeconomic variables then interest rate rules in the long run. This is different from Corsetti et al. (2017), who argues that flexible exchange rate regimes perform better then a fixed exchange rate regime when the domestic economy faces a negative demand shock (level shock) from abroad. This happens because a flexible exchange rate regime stabilises the demand via depreciation of the domestic currency which a PEG regime does not allow for. This is in contrast to the results we get in this chapter for a second moment shock to the demand abroad. The difference in the results is primarily driven by non-zero risk premiums generated for second moment shocks as UIP does not hold. Since flexible exchange rate regimes are associated with higher risk premiums than PEG, the latter performs better under high global uncertainty.[7]

We find that a monetary policy rule that gives the lowest welfare losses when a small open economy is hit with a global uncertainty shock is an exchange rate rule. When a monetary policy uses the exchange rate as an instrument, the exchange rate follows a rule and is guided by key fundamentals governing the domestic economy, like inflation and output. Since the exchange rate follows a rule and does not float freely, the hedging

[7]In Corsetti et al. (2017) a depreciation of domestic currency stabilizes demand. This paper looks at two other channels of depreciation which can affect an economy adversely in the baseline case of flexible exchange rates. Firstly when the domestic currency depreciates this increases inflation in the domestic country. Assuming the domestic country is an inflation targeter and is not at the zero lower bound (ZLB) constraint (the EMEs considered here are not at the ZLB constraint), monetary policy increases the policy rate which has a negative affect on domestic demand. The second channel is the fall in the investment demand and drying up of the working capital in domestic firms due to depreciation, as discussed in the Introduction to this chapter.

motive mentioned above is weakened. Thus, nominal exchange rates are stabilized and welfare losses are reduced significantly. Heiperzt et al. (2017) also show that exchange rate rules outperform interest rate rules in a small open economy for shocks to the first moment. The risk premiums associated with exchange rate rules are also lower, due to a lower hedging motive. At the same time, a link between monetary policy, exchange rates and key real macro variables like inflation and output is restored. Exchange rate rules not only reduce welfare losses but also reduce the variability of nominal exchange rates, output and inflation remarkably. The right chart in Figure 4-1 shows how a link between monetary policy, exchange rates and key real macro variables like inflation and output is restored when exchange rate rules are followed. Exchange rate rules not only reduce welfare losses but also reduce the variability of nominal exchange rates, output and inflation remarkably.

4.1.1 Empirical evidence

We use a local projection method proposed by Jorda (2005) to look for the effects of global uncertainty shocks on a wide variety of variables for both AEs and EMEs.[8] To capture global uncertainty we use the VXO index series as proxied in Bloom (2009) and Cespedes and Swallow (2013). For the VXO series, we use the CBOE S&P 100 Volatility Index's daily series accessed from the Federal Reserve Bank of St. Louis database from 1996 to 2018.[9] For further analysis, we create a quarterly panel dataset for 12 economies from 1996:Q1 to 2018:Q4. We consider six AEs (US, UK, Canada, Japan, Australia and South Korea) and six EMEs (Brazil, Indonesia, India, Mexico, Russia and South Africa).[10] The primary source for most of the macroeconomic series is the quarterly national accounts

[8] We use STATA 13 to do our empirical analysis.

[9] Chicago Board Options Exchange, CBOE S&P 100 Volatility Index: VXO [VXOCLS], is retrieved from FRED, Federal Reserve Bank of St. Louis;
https://fred.stlouisfed.org/series/VXOCLS, January 10, 2019.

[10] The choice of EMEs depends on availability of data. For AEs we choose six large economies. All the series are seasonally adjusted using X-12-ARIMA routine provided by the U.S. Census Bureau, and detrended using the Hodrick–Prescott filter.

data compiled by the Organization for Economic Cooperation and Development (OECD). The macroeconomic series we consider are: real GDP, real consumption, real investment, trade balance, nominal exchange rate, real effective exchange rate and short term interest rates.[11] We get the country wise series on net portfolio investment from the International Monetary Fund's International Financial Statistics (IFS).[12] A detailed data description is provided in the Data Appendix C.1.

We estimate panel local projections for horizon, $h = 0, 1, 2, 3, 4, 5, 6$ as described below,

$$Y_{i,t+h} - Y_{i,t-1} = \alpha_{i,h} + \theta_{i,h} vxo_t + \sum_q \beta^q_{i,h} X_{i,t-q} + \varsigma_{i,t+h}$$

Here, for country i, $\varsigma_{i,t+h}$ is the projection residual, $\alpha_{i,h}$, $\theta_{i,h}$ and $\beta^q_{i,h}$ are the projection coefficients. The vector Y_t is a set of response variables including real GDP, real consumption, real investment, the trade balance, the nominal exchange rate, the real effective exchange rate, net portfolio investment, inflation and short term interest rates. The vector X_t is a set of control variables including lagged dependent variables and policy variables. The local projection impulse response of Y_t with respect to vxo_t at horizon h for country i is given by $\{\theta_{i,h}\}$ for $h \succeq 0$. The lag of control variables, q, is set to upto four periods. We control for the country fixed effects in our panel regression.

[INSERT FIGURES 4-2, 4-3, 4-4 and 4-5]

Figures 4-2, 4-3, 4-4 and 4-5 show local projection responses using OLS for six quarters after the shock to global uncertainty.[13] We plot impulse response functions with 90 per cent and 80 per cent confidence bands. Figures 4-2a and 4-2b show the response of GDP and private consumption to an increase in global uncertainty. GDP and private consumption decrease in both EMEs and AEs, but the decrease is much higher (upto

[11]Data is accessed in January, 2019 from https://stats.oecd.org/#

[12]Data is accessed in January, 2018 from http://data.imf.org/?sk=388DFA60-1D26-4ADE-B505-A05A558D9A42&sId=1479329334655

[13]The values on the y-axis show a percentage change from the trend. All the graphs are local projection responses with VXO impulse for EMEs (on the left) and AEs (on the right) using OLS. No single country is driving the results in the robustness checks.

10 per cent from the trend) in EMEs compared to AEs. This result is consistent with the empirical fact observed in Cespedes and Swallow (2013). Figure 4-3a shows capital (net portfolio investment) outflows from EMEs immediately after the shock.[14] About 30 per cent of the capital, as a deviation from the trend, in EMEs flows out when global uncertainty increases. AEs do not experience much change in there capital movement as compared to EMEs. The literature has identified global risk as one of the most important push factors in determining capital outflows from EMEs (see Fratzscher (2012), Forbes and Warnock (2012)). As a result of capital outflows, the domestic currency (nominal exchange rate) in EMEs depreciates up to 10 per cent in two quarters after the shock (see Figure 4-4a). The real effective exchange rate (REER) also depreciates and remains depreciated up to four quarters after the shock in EMEs (see Figure 4-4b).[15] No significant exchange rate movements are observed in AEs as compared to EMEs. A sustained real or nominal depreciation of the currency amplifies the reduction in real activity and brings instability to the business cycle in EMEs as argued in Korinek (2018) and Cook (2004).

The primary reason emphasized in papers mentioned above is the presence of large external debt denominated in foreign currency in EMEs. When the currency depreciates, balance sheets of firms in EMEs worsens, and this leads to foreign investors pulling out their investments. EMEs also experience a trade deficit in the first two quarters after a shock before the trade balance starts improving due to currency depreciation (see Figure 4-3a).[16] Initially, the trade balance falls due to a fall in foreign demand for domestic goods (exports) as consumption in the foreign economy is also low due to higher global uncertainty. Currency depreciation in EMEs leads to a rise in inflation due to a rise in the import good price (see Figure 4-5a). AEs on the other hand, experience a

[14]The series used here is net portfolio investment to GDP ratio. This is done to normalize the series before HP filtering.

[15]Since the REER is measure in terms of US dollars, any decrease here indicates real effective depreciation.

[16]Series used here is the trade balance to GDP ratio. This is done to normalize the series before HP filtering.

fall in consumer prices as their aggregate demand falls (see Figure 4-5b). All countries considered for the present analysis have an inflation targeting mandate with interest rates as a monetary policy instrument. Interest rates thus fall in AEs as a policy response to a contracting economy and deflation (Figure 4-5a).[17] For EMEs, a contracting economy would suggest reduction in the interest rates (expansionary monetary policy), and an increase in consumer prices with exchange rate depreciation would suggest an increase in the interest rates (contractionary monetary policy). Policymakers in EMEs are thus faced with the trade-off between inflation and the output stabilization. Moreover, as the central bank gives more weight to stabilizing inflation in a Taylor type interest rate rule, we observe an increase in the interest rates in EMEs (see Figure 4-5a).

Summary of stylized facts

The empirical observations explained above can be summarized as following stylized facts:

Fact 1: An increase in global uncertainty reduces real activity in both AEs as well as EMEs. EMEs experience a greater fall in GDP and private consumption compared to AEs and also take more time to recover from the shock.

Fact 2: An increase in global uncertainty pulls capital (net portfolio investment) out from EMEs. The trade balances deteriorates initially before improving due to an exchange rate depreciation.

Fact 3: The capital outflow from EMEs leads to a currency (both nominal and real exchange rates) depreciation. As has been emphasized in the literature, an exchange rate depreciation worsens the balance sheets of firms, which is followed by foreign investors pulling out capital further and thus amplifying the effect of the shock on the real economy.

Fact 4: Consumer prices in EMEs increase due to a depreciation, and monetary policy responds by increasing interest rates. A rise in interest rates can thus reinforce

[17]Impulse responses for real GDP, real consumption, the trade balance,the real effective exchange rate, inflation and short term interest rates are strongly significant at the 90 per cent confidence level. On the other hand, net portfolio investment and the nominal exchange rate are significant nearly at the 80 per cent confidence level. We suspect this happens due to the averaging out effect in the movement of portfolio investments and exchange rates over a quarter.

the adverse effects of global uncertainty shock on the real economy.

To explain these facts and understand the role of monetary policy, we build a small open economy NK-DSGE model with uncertainty shocks. The basic framework of the model is adapted from the two country model (foreign and domestic country) discussed in Benigno et al. (2012). While we characterize the domestic economy as a small open economy, the foreign economy is an approximation to the world economy. The uncertainty is present in the preference/ demand shock of households in the foreign economy. We calibrate a small open economy and the world economy to a prototypical EME and AE, respectively.

4.1.2 Main results

Response to an uncertainty shock to the demand

We find that the calibration results from the model fit well qualitatively with the empirical stylized facts we observe in the data. When a global uncertainty shock hits a SOE, they experience a sudden capital outflow of capital and their nominal exchange rates depreciate. The real effective exchange rates (REER) also depreciates following a nominal exchange rate depreciation. This result is consistent with stylized Fact 3 we observe in the data. Demand contracts in the economy as agents save more (precautionary savings motive) and consume less today in a demand determined new-Keynesian model. Net exports rise due to a fall in imports as a result of the depreciation. This result is in line with empirical Facts 1 and 2, although in the data we observe the trade balance improving only after two quarters. Due to a depreciation of the domestic currency, the import prices of foreign goods consumed by domestic households increases. This increases consumer price inflation in the domestic economy. Since the central bank follows a simple Taylor type interest rate rule, the nominal interest rate also rises to stabilize consumer price inflation in the domestic country. This result too qualitatively matches Fact 4 that we observe in the data. The welfare losses in the domestic economy are positive because of adverse real effects of the shock.

We also find that the level of price flexibility matters for the extent to which uncertainty shock affect real variables. Under complete price flexibility, real variables are not affected and only nominal variables adjust. This happens because the economy under flexible price equilibrium is supply determined and not demand determined. When savings increase due to an uncertainty shock, the supply side of the economy is unaffected. Only the price level and the nominal interest rate adjusts here. As a result when savings (in assets) go out of the country, with increasing uncertainty, the price of the asset in domestic country falls. This fall in the asset prices leads to a rise in the nominal rate of interest. Consumer prices also increase to ensure that real savings and real interest rate do not show any change in the new equilibrium.

Role of monetary policy

A positive response of interest rates can reinforce the adverse effects of uncertainty shocks on the real economy. Moreover, the interest rate response is ineffective in stabilizing exchange rates, both nominal and real, as the UIP breaksdown. Further, to examine the role of monetary policy in stabilizing the effects of a global uncertainty shock, we compare impulse responses from the model under alternate monetary policy rules. We broadly consider two categories of monetary policy rules. The first category rules are modified Taylor type interest rate rules. The second category rules are exchange rate rules. Under exchange rate rules, monetary policy is conducted with exchange rates as a monetary policy instrument. We also consider an extreme case of complete exchange rate stabilization i.e. a fixed exchange rate / PEG rule.

We find that welfare losses are lowest in exchange rate rules, followed by a PEG rule. The Taylor type interest rate rules give highest welfare losses. The welfare losses are reduced upto 21 per cent when a central bank switches to following an exchange rate rule from an interest rate rule. Comparing second order moments in long run simulations from the model under different rules show a remarkable reduction in the variability of variables when exchange rate rules are followed. To be specific, the standard deviation of the nominal exchange rate, output and consumer price inflation (CPI) is reduced by 85 per cent, 36 per cent and 45 per cent, respectively, when exchange rate rules are followed instead of interest rate rules.

This happens primarily because with a flexible exchange regime and monetary policy following an interest rate rule, uncovered interest parity (UIP) condition does not hold. Under increasing global uncertainty, the movement of nominal exchange rates is guided by a hedging motive, instead of interest rates. In other words, the link between exchange rates and interest rates breaks down and uncovered interest rate parity no longer holds. This gives rise to a non-zero time varying risk premium. When monetary policy follows an exchange rate rule, the hedging motive is weak and the movement of the exchange rates is controlled by a rule. This rule restores the lost connection between monetary policy, exchange rates, inflation and output, thus making monetary policy rules effective in stabilizing the economy. Moreover with exchange rate rules, the precautionary motive to save and thus consume less is weak since exchange rate rules are associated with lower risk premiums. This reduces transmission of uncertainty shocks on the real economy through the aggregate demand channel.

4.2 The Model

Our model is a two-country (domestic and foreign) open economy NK-DSGE model. The domestic country represents an emerging market economy, which is modelled here as a small open economy, and the foreign country represents an advanced economy. The basic framework of the model is adapted from Benigno et al. (2012) with the following modifications. First, in our model the domestic economy is characterized as a small open economy and the foreign economy is thus an approximation to the world economy.[18] Second, we consider a simple preference structure for households following Fernández-

[18]Benigno et al. (2012) consider the case of two large economies in their paper.

Villaverde et al. (2011), rather than a recursive preference structure.[19] Third, we have a second-moment shock (uncertainty shock) on the productivity and the demand processes of only the foreign/ world economy. We do this because the foreign economy represents the world here due to its size and we are interested in effects of global uncertainty shocks on the small open economy. Fourth, we follow Fernández-Villaverde et al. (2011) and take a third-order approximation of the model to solve it. Benigno et al. (2012) follows an approach discussed in Benigno et al. (2013) and take a second-order approximation to solve the model and capture the effects of second-moment shocks.

4.2.1 Households

The world is assumed to consist of two countries, domestic (D) and foreign (F). We assume that domestic economy is a small open economy with size n relative to the world economy, which is modelled as a foreign economy.[20] A continuum of domestic households exist over $[0, n]$, while foreign households from $(n, 1]$, where $n \in (0, 1)$. An agent in each country is both a consumer and a producer, producing a single differentiated good and consuming all the goods produced in both countries. Also, the population size in each country is set equal to the range of goods produced in that country, such that domestic firms produce goods on $[0, n]$, and foreign firms produce goods on $(n, 1]$. The preferences of a representative household in domestic country is captured by the following utility function,

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{(C_t)}{1-\nu_D}^{1-\nu_D} - \omega_D \frac{(H_{D,t})}{1+\eta_D}^{1+\eta_D} \right). \tag{4.1}$$

Here C_t denotes the aggregate consumption index, $H_{D,t}$ denotes hours worked by the representative domestic household, ν_D is a measure of the inverse of the intertemporal elasticity of substitution, η_D is the inverse of the Frisch elasticity of substitution, and

[19] We also assume that the elasticity of substitution between domestic goods and foreign goods is different for domestic and foreign households in our model. But later we calibrate the model for the same values due to limited empirical evidence on the same.

[20] We later limit $n \to 0$ to characterize the domestic economy as a small open economy.

$\beta \in (0,1)$ is the discount factor. The aggregate consumption index, C_t, is defined as,

$$C_t = \left[(\mu_D)^{1/\xi_D} (C_{D,t})^{\frac{\xi_D - 1}{\xi_D}} + (1-\mu_D)^{1/\xi_D} (C_{F,t})^{\frac{\xi_D - 1}{\xi_D}} \right]^{\frac{\xi_D}{\xi_D - 1}} \tag{4.2}$$

where, $C_{D,t}$ and $C_{F,t}$ denotes the consumption index of domestic goods and foreign goods of domestic households, respectively. $\xi_D > 0$ is the elasticity of substitution between domestic goods and foreign goods for domestic households and $\mu_D \in (0,1)$ is the weight given to domestic goods in the aggregate consumption basket, C_t.[21] Analogous to equation (4.1), the utility function for a representative household in a foreign country is given by,

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{\Gamma_{F,t} (C_t^*)^{1-\nu_F}}{1-\nu_F} - \omega_F \frac{(H_{F,t})^{1+\eta_F}}{1+\eta_F} \right) \tag{4.3}$$

where C_t^* denotes the aggregate consumption index, $H_{F,t}$ denotes hours worked and $\Gamma_{F,t}$ is the preference/ demand shock process. The aggregate consumption bundle C_t^* is given by,

$$C_t^* = \left[(\mu_F)^{1/\xi_F} \left(C_{D,t}^*\right)^{\frac{\xi_F - 1}{\xi_F}} + (1-\mu_F)^{1/\xi_F} \left(C_{F,t}^*\right)^{\frac{\xi_F - 1}{\xi_F}} \right]^{\frac{\xi_F}{\xi_F - 1}} \tag{4.4}$$

where $\mu_F \in (0,1)$ is weight given to domestic goods in the aggregate consumption basket, C_t^*. Following Benigno et al. (2012), the weights mentioned in the aggregate consumption bundles equations (4.2) and (4.4) are related to country sizes through:

$$1 - \mu_D = (1-n)\chi \tag{4.5}$$

$$\mu_F = n\chi. \tag{4.6}$$

Here, $\chi \in (0,1)$ is the (common) degree of openness between the domestic and foreign country. When $\chi = 0$, there is no trade of either goods or assets happening across the two countries and it represents an autarky case. $\chi = 1$, represents a case of complete free

[21]When $\nu_D > n$ means a home-bias for domestic goods since the weight given to domestic goods is higher than the size of the country.

trade of both goods and assets between the two countries. Consumption bundles, $C_{D,t}$, $C_{F,t}, C^*_{D,t}$ and $C^*_{F,t}$ are Dixit-Stiglitz aggregates of differentiated goods produced in two countries and are defined as,

$$C_{D,t} = \left[\left(\frac{1}{n}\right)^{\frac{1}{\sigma}} \int_0^n \left(C_{D,t}(i)\right)^{\frac{\sigma-1}{\sigma}} di\right]^{\frac{\sigma}{\sigma-1}} ; C_{F,t} = \left[\left(\frac{1}{1-n}\right)^{\frac{1}{\sigma}} \int_n^1 \left(C_{F,t}(i)\right)^{\frac{\sigma-1}{\sigma}} di\right]^{\frac{\sigma}{\sigma-1}} \quad (4.7)$$

$$C^*_{D,t} = \left[\left(\frac{1}{n}\right)^{\frac{1}{\sigma}} \int_0^n \left(C^*_{D,t}(i)\right)^{\frac{\sigma-1}{\sigma}} di\right]^{\frac{\sigma}{\sigma-1}} ; C^*_{F,t} = \left[\left(\frac{1}{1-n}\right)^{\frac{1}{\sigma}} \int_n^1 \left(C^*_{F,t}(i)\right)^{\frac{\sigma-1}{\sigma}} di\right]^{\frac{\sigma}{\sigma-1}} \quad (4.8)$$

Here σ is the elasticity of substitution between the varieties, where a variety is indexed by $i \in [0,1]$.[22] The demand for each variety of a differentiated domestic and foreign good by each country's household is given as follows,[23]

$$C_{D,t}(i) = \left(\frac{1}{n}\right)\left(\frac{P_{D,t}(i)}{P_{D,t}}\right)^{-\sigma} C_{D,t} ; C_{F,t}(i) = \left(\frac{1}{1-n}\right)\left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\sigma} C_{F,t} \quad (4.9)$$

$$C^*_{D,t}(i) = \left(\frac{1}{n}\right)\left(\frac{P^*_{D,t}(i)}{P^*_{D,t}}\right)^{-\sigma} C^*_{D,t} ; C^*_{F,t}(i) = \left(\frac{1}{1-n}\right)\left(\frac{P^*_{F,t}(i)}{P^*_{F,t}}\right)^{-\sigma} C^*_{F,t} \quad (4.10)$$

where, $P_{D,t}(i)$ and $P^*_{D,t}(i)$ are prices of a variety i of a good produced in the domestic country in domestic and foreign currency, respectively. Similarly, $P_{F,t}(i)$, and $P^*_{F,t}(i)$ are prices of a variety i of a good produced in the foreign country in domestic and foreign currency, respectively. $P_{D,t}$, $P_{F,t}$, $P^*_{D,t}$ and $P^*_{F,t}$ are the price aggregates of the aggregate

[22] Note that the elasticity of substitution between the varieties, σ, is assumed to be same in both the countries.

[23] Refer to the Technical Appendix C.2 for derivations.

consumption baskets, $C_{D,t}$, $C_{F,t}$, $C^*_{D,t}$ and $C^*_{F,t}$, respectively and are defined as follows,

$$P_{D,t} = \left[\left(\frac{1}{n}\right)\int_0^n P_{D,t}(i)^{1-\sigma}\,di\right]^{\frac{1}{1-\sigma}} \; ; \; P_{F,t} = \left[\left(\frac{1}{1-n}\right)\int_n^1 P_{F,t}(i)^{1-\sigma}\,di\right]^{\frac{1}{1-\sigma}} \quad (4.11)$$

$$P^*_{D,t} = \left[\left(\frac{1}{n}\right)\int_0^n P^*_{D,t}(i)^{1-\sigma}\,di\right]^{\frac{1}{1-\sigma}} \; ; \; P^*_{F,t} = \left[\left(\frac{1}{1-n}\right)\int_n^1 P^*_{F,t}(i)^{1-\sigma}\,di\right]^{\frac{1}{1-\sigma}} \quad (4.12)$$

The law of one price is assumed to hold across all individual goods, such that, $P_{D,t}(i) = X_t P^*_{D,t}(i)$, and $P_{F,t}(i) = X_t P^*_{F,t}(i)$, where X_t is the nominal exchange rate (price of foreign currency in terms of domestic currency). Using this relation with the price aggregates in equations (4.11) and (4.12) we also get, $P_{D,t} = X_t P^*_{D,t}$ and $P_{F,t} = X_t P^*_{F,t}$. Demand functions for the consumption aggregates, $C_{D,t}$, $C_{F,t}$, $C^*_{D,t}$ and $C^*_{F,t}$ are as follows,

$$C_{D,t} = \mu_D\left(\frac{P_{D,t}}{P_t}\right)^{-\xi_D} C_t \; ; \; C_{F,t} = (1-\mu_D)\left(\frac{P^*_{F,t}}{P^*_t}\right)^{-\xi_D} C_t, \quad (4.13)$$

$$C^*_{D,t} = \mu_F\left(\frac{T_{D,t}}{Q_t}\right)^{-\xi_F} C^*_t \; ; \; C^*_{F,t} = (1-\mu_F)\left(\frac{P^*_{F,t}}{P^*_t}\right)^{-\xi_F} C^*_t \quad (4.14)$$

where, P_t and P^*_t are the aggregate consumer price indices (CPI) in the domestic and foreign country, in domestic and foreign currency, respectively, and are defined as,

$$P_t = \left[\mu_D (P_{D,t})^{1-\xi_D} + (1-\mu_D)(P_{F,t})^{1-\xi_D}\right]^{\frac{1}{1-\xi_D}} \quad (4.15)$$

$$P^*_t = \left[\mu_F \left(P^*_{D,t}\right)^{1-\xi_F} + (1-\mu_F)\left(P^*_{F,t}\right)^{1-\xi_F}\right]^{\frac{1}{1-\xi_F}} \quad (4.16)$$

It can be seen that due to a heterogenous preference structure across the two countries, purchasing power parity (PPP) does not hold at the aggregate price levels, such that $P_t \neq X_t P^*_t$. PPP holds only when $\mu_D = \mu_F$ and $\xi_D = \xi_F$. Benigno et al. (2012) assume $\mu_D \neq \mu_F$, such that PPP does not hold in their model too. Any deviations from PPP are measured through the real exchange rate, which is defined as the ratio of consumer price indices in the two countries in terms of domestic prices, and is given by,

$$Q_t = \frac{X_t P_t^*}{P_t}. \tag{4.17}$$

Re-writing equation (4.17) gives us the following relationship between consumer price inflation in the domestic and foreign country,

$$\pi_t^* = \pi_t \frac{Q_t}{Q_{t-1}\pi_{X,t}}. \tag{4.18}$$

Here, consumer price inflation in the foreign country and domestic country are defined as $\pi_t^* = \frac{P_t^*}{P_{t-1}^*}$ and $\pi_t = \frac{P_t}{P_{t-1}}$, respectively. Also, the change in the nominal exchange rate is defined as, $\pi_{X,t} = \frac{X_t}{X_{t-1}}$. The terms of trade is defined as a ratio of foreign prices to domestic prices, where both price indices are denominated in domestic currency and is given by,

$$\begin{aligned} T_t &= \frac{P_{F,t}}{P_{D,t}} \\ &= \frac{T_{F,t}}{T_{D,t}} \end{aligned} \tag{4.19}$$

where we define relative price ratios, $T_{D,t} = \frac{P_{D,t}}{P_t}$ and $T_{F,t} = \frac{P_{F,t}}{P_t}$. Using these definitions of relative price ratios with equation (4.15), we get the following relation,

$$T_{F,t} = \left[\frac{1 - \mu_D \left(T_{D,t}\right)^{1-\xi_D}}{1 - \mu_D}\right]^{\frac{1}{1-\xi_D}}. \tag{4.20}$$

Similarly, equation (4.16) can be re-written in terms of gross foreign inflation $\left(\pi_{F,t}^*\right)$, foreign consumer price inflation (π_t^*), and the terms of trade as,

$$\pi_t^* = \pi_{F,t}^* \left[\frac{\mu_F \left(T_t\right)^{\xi_F - 1} + (1 - \mu_F)}{\mu_F \left(T_{t-1}\right)^{\xi_F - 1} + (1 - \mu_F)}\right]^{\frac{1}{1-\xi_F}} \tag{4.21}$$

where, $\pi^*_{F,t} = \frac{P^*_{F,t}}{P^*_{F,t-1}}$. For the above described preferences, the total demand for each variety i of the domestic produce is given by,

$$Y_{D,t}(i) = nC_{D,t}(i) + (1-n)\, C^*_{D,t}(i)$$

where $nC_{D,t}(i)$ and $(1-n)\, C^*_{D,t}(i)$ is the aggregate demand of all households in the domestic and foreign country, respectively, for variety i of the domestic produce. Using the demand functions described in (4.9) and (4.10), we get

$$Y_{D,t}(i) = \left(\frac{P_{D,t}(i)}{P_{D,t}}\right)^{-\sigma} Y_{D,t} \tag{4.22}$$

where, aggregate demand for domestic good (all varieties) is given by, $Y_{D,t} = C_{D,t} + \left(\frac{1-n}{n}\right) C^*_{D,t}$. Further, using (4.13) and (4.14) in equation (4.22), we can re-write $Y_{D,t}$ in terms of aggregate consumption bundles in the two countries, as given by

$$Y_{D,t} = (T_{D,t})^{-\xi_D} \left[\mu_D C_t + \left(\frac{1-n}{n}\right) \mu_F Q_t^{\xi_F} (T_{D,t})^{\xi_D - \xi_F} C^*_t\right] \tag{4.23}$$

Similar to the domestic country, aggregate demand for a variety i of the foreign good is given by,

$$Y_{F,t}(i) = \left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\sigma} Y_{F,t} \tag{4.24}$$

where, aggregate demand for the foreign good (all varieties), $Y_{F,t} = \frac{n}{(1-n)} C_{F,t} + C^*_{F,t}$. Aggregate demand, $Y_{F,t}$, can be re-written in terms of aggregate consumption bundles in the two countries as,

$$Y_{F,t} = (T_{F,t})^{-\xi_D} \left[\frac{n}{(1-n)} (1-\mu_D)\, C_t + (1-\mu_F)\, Q_t^{\xi_F} (T_{F,t})^{\xi_D - \xi_F} C^*_t\right] \tag{4.25}$$

Households in the domestic and foreign country maximize (4.1) and (4.3) subject to the following flow budget constraints,

$$W_{D,t}H_{D,t} + \varpi_{D,t} \geq P_tC_t - B_{D,t} + E_t\left\{B_{D,t+1}M_{t,t+1}\right\}, \quad (4.26)$$

$$W_{F,t}H_{F,t} + \varpi_{F,t} \geq P_t^*C_t^* - B_{F,t} + E_t\left\{B_{F,t+1}M_{t,t+1}^*\right\} \quad (4.27)$$

respectively. Here $W_{D,t}$ and $W_{F,t}$ are nominal wages in the domestic and foreign country, respectively. The nominal wages are decided in a common labour market in each country. Also, $\varpi_{D,t}$ and $\varpi_{F,t}$ are the nominal profits which households receive from owning monopolistically competitive firms in the domestic and foreign country, respectively. Each household in each country holds equal shares in all firms and there is no trade in firm shares. The asset markets are assumed to be complete both at domestic and at international levels. Households trade in state-contingent nominal securities denominated in the domestic currency. $B_{D,t+1}$ is the state-contingent payoff at time $t+1$ of a portfolio of state-contingent nominal securities held by a household in the domestic country at the end of period t. The value of this portfolio can be written as $E_t\left\{B_{D,t+1}M_{t,t+1}\right\}$, where $M_{t,t+1}$ is the nominal stochastic discount factor for discounting wealth denominated in the domestic currency.

Households in the foreign country also trade in state-contingent securities denominated in the domestic currency. Let B_{t+1} be the state-contingent payoff (denominated in domestic currency) in period $t+1$ of the state-contingent portfolio held by foreign households at the end of period t. The payoff in the foreign currency in period $t+1$ is given by, $B_{F,t+1} = \frac{B_{t+1}}{X_{t+1}}$. Also the value of the portfolio today in foreign currency in period t is given by $\frac{E_t\{B_{t+1}M_{t,t+1}\}}{X_t} = \frac{E_t\left\{B_{F,t+1}X_{t+1}M_{t,t+1}\right\}}{X_t}$. The nominal stochastic discount factor for discounting wealth denominated in the foreign currency can thus be defined as,

$$M_{t,t+1}^* = \frac{X_{t+1}}{X_t}M_{t,t+1}. \quad (4.28)$$

The first order conditions for maximizing utility functions (4.1) and (4.3) for consumption

(C_t, C_t^*), labour $(H_{D,t}, H_{F,t})$ and asset holdings $(B_{D,t+1,}B_{F,t+1})$ subject to the flow budget constraints (4.26) and (4.27) respectively are given by:

$$\begin{aligned}
\text{Euler's equation } (D) \quad &: \quad \beta\frac{E_t\left\{C_{t+1}^{-\nu_D}\right\}}{C_t^{-\nu_D}} = E_t\left\{M_{t,t+1}\pi_{t+1}\right\} \\
&\Rightarrow \quad \beta\frac{E_t\left\{C_{t+1}^{-\nu_D}\right\}}{C_t^{-\nu_D}} = \frac{E_t\left\{\pi_{t+1}\right\}}{(1+R_t)} \qquad (4.29)
\end{aligned}$$

$$\begin{aligned}
(F) \quad &: \quad \beta\frac{E_t\left\{\Gamma_{F,t+1}C_{t+1}^{*-\nu_F}\right\}}{\Gamma_{F,t}C_t^{*-\nu_F}} = E_t\left\{M_{t,t+1}^*\pi_{t+1}^*\right\} \\
&\Rightarrow \quad \beta\frac{E_t\left\{\Gamma_{F,t+1}C_{t+1}^{*-\nu_F}\right\}}{\Gamma_{F,t}C_t^{*-\nu_F}} = \frac{E_t\left\{\pi_{t+1}^*\right\}}{(1+R_t^*)} \qquad (4.30)
\end{aligned}$$

$$\text{Labour supply equation } (D) \quad : \quad w_{D,t} = \frac{\omega_D\left(H_{D,t}\right)^{\eta_D}}{\left(C_t\right)^{-\nu_D}T_{D,t}} \qquad (4.31)$$

$$(F) \quad : \quad w_{F,t} = \frac{\omega_F\left(H_{F,t}\right)^{\eta_F}Q_t}{\Gamma_{F,t}\left(C_t^*\right)^{-\nu_F}T_{F,t}} \qquad (4.32)$$

Here, the gross nominal interest rate in domestic country is given by, $(1+R_t) = \frac{1}{E_t\{M_{t,t+1}\}}$ and the gross nominal interest rate in foreign country is given by, $(1+R_t^*) = \frac{1}{E_t\left\{M_{t,t+1}^*\right\}}$. Real wages in the domestic and foreign country are defined respectively as, $w_{D,t} = \frac{W_{D,t}}{P_{D,t}}$ and $w_{F,t} = \frac{W_{F,t}}{P_{F,t}}$. We also define the Lagrangian multiplier denoting the marginal utility of income for the above maximization exercise as,

$$\lambda_{D,t} = \left(C_t\right)^{-\nu_D} \quad ; \lambda_{F,t} = \Gamma_{F,t}\left(C_t^*\right)^{-\nu_F} \qquad (4.33)$$

Here $\lambda_{D,t}$ and $\lambda_{F,t}$ are Lagrangian multipliers for domestic and foreign country households, respectively. Combining the Euler equation from equation (4.29) and (4.30) with equation (4.28), we get the following complete asset market condition,

$$Q_{t+1} = \kappa\frac{E_t\left\{\Gamma_{F,t+1}C_{t+1}^{*-\nu_F}\right\}}{E_t\left\{C_{t+1}^{-\nu_D}\right\}}. \qquad (4.34)$$

where, $\kappa = Q_0 \frac{C_0^{-\nu_D}}{\Gamma_{F,0} C_0^{*-\nu_F}}$ is the ratio of marginal utilities of nominal income across countries in the initial period. Equation (4.28) when combined with definitions of nominal stochastic discount factors i.e. $E_t \{M_{t,t+1}\} = \frac{1}{(1+R_t)}$ and $E_t \{M^*_{t,t+1}\} = \frac{1}{(1+R^*_t)}$, gives the following uncovered interest rate parity (UIP) condition,

$$(1 + R_t) = E_t \left\{ \frac{X_{t+1}}{X_t} \right\} (1 + R^*_t) \tag{4.35}$$

Following Menkhoff et al. (2012), Backus et al. (2010) and Benigno et al. (2012), we define time-varying risk premiums as deviations from the UIP condition, mentioned in equation (4.35). The log-linearized time-varying risk premiums, rp_t, are excess returns on holding domestic currency and written as follows,

$$rp_t = r_t - r^*_t - E_t \{\Delta x_{t+1}\}, \tag{4.36}$$

where, r_t, r^*_t and $E_t \{\Delta e_{t+1}\}$ are logs of $(1 + R_t)$, $(1 + R^*_t)$ and $E_t \left\{ \frac{X_{t+1}}{X_t} \right\}$, respectively.

4.2.2 Firms

The domestic country produces goods on the interval $[0, n]$ and the foreign country on $(n, 1]$. A firm producing variety i of a good in the domestic and foreign country follows a production function linear in labour, given by,

$$Y_{D,t}(i) = A_{D,t} H_{D,t}(i) \tag{4.37}$$

$$Y_{F,t}(i) = A_{F,t} H_{F,t}(i), \tag{4.38}$$

respectively. Here, $A_{D,t}$ and $A_{F,t}$ are the productivity levels (common) following exogenous processes. $H_{D,t}(i)$ and $H_{F,t}(i)$ are composites of all the differentiated labour supplied by household h in each country, as given by,

$$H_{D,t}(i) = \frac{1}{n} \int_0^n H^h_{D,t}(i)\ dh\ ;\ H_{F,t}(i) = \frac{1}{1-n} \int_n^1 H^h_{F,t}(i)\ dh \tag{4.39}$$

where $H^h_{D,t}(i)$ and $H^h_{F,t}(i)$ are the labour supplied by household h to firm i in the domestic and foreign country, respectively.

Price setting

In the benchmark model we assume that firms in both the countries have nominal price rigidities in the form of price stickiness. We follow Calvo (1983) to capture price stickiness here. In each period only $(1-\alpha_D)$ fraction of firms in the domestic country can reset their prices independent of whether they had a chance to reset them in the last period. A firm i which gets a chance to reset its prices, $\overline{P}_{D,t}(i)$, maximizes a discounted sum of current and future expected values of profit, given by

$$\max_{\overline{P}_{D,t}(i)} \sum_{k=0}^{\infty} \alpha_D^k M_{t,t+k} \left(\overline{P}_{D,t}(i) Y_{D,t_{+k}}(i) - MC_{D,t+k} Y_{D,t_{+k}}(i) \right) \tag{4.40}$$

where $MC_{D,t+k}$ is the nominal marginal cost of domestic firms in period $t+k$ and is the same for all firms as the nominal wage is decided in a common labour market and all firms face a common productivity level realization. The demand function $Y_{D,t+k}(i)$, for each firm i in period $t+k$ is given by,

$$Y_{D,t+k}(i) = \left(\frac{\overline{P}_{D,t}(i)}{P_{D,t+k}} \right)^{-\sigma} Y_{D,t+k}$$

The optimal price chosen by firms re-setting prices is given by,

$$\overline{P}_{D,t}(i) = \frac{\sigma}{\sigma-1} \frac{\sum\limits_{k=0}^{\infty} \alpha_D^k M_{t,t+k} MC_{D,t+k} Y_{D,t+k}(i)}{\sum\limits_{k=0}^{\infty} \alpha_D^k M_{t,t+k} Y_{D,t+k}(i)} \tag{4.41}$$

where $\frac{\sigma}{\sigma-1}$ is the constant markup charged by firms. As can be seen from equation (4.41), the optimal price today depends on not just current but future marginal costs, and also demand conditions in the economy. A firm i, which does not reset its price is assumed to keep the prices same as last year's prices, $P_{D,t-1}(i)$. Thus, the law of motion for the aggregate producers price index (PPI) in the domestic country for Calvo's model can be written as,

$$P_{D,t} = \left[\alpha_D \left(P_{D,t-1}\right)^{1-\sigma} + (1-\alpha_D)\left(\overline{P}_{D,t}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}. \tag{4.42}$$

Using the domestic household's optimization problem we can write the stochastic discount factor $M_{t,t+k}$ as,

$$M_{t,t+k} = \beta^k \frac{\lambda_{D,t+k}}{\lambda_{D,t}} \frac{P_t}{P_{t+k}} \tag{4.43}$$

where $\lambda_{D,t}$ is the Lagrangian multiplier denoting the marginal utility of income. Combined with equation (4.43) , the price setting equation (4.41) can be written recursively as,

$$\overline{\pi}_{D,t} = \frac{\sigma}{\sigma-1}\pi_{D,t}\frac{X_{D,t}}{Z_{D,t}} \tag{4.44}$$

where $X_{D,t}$ and $Z_{D,t}$ are defined as follows,

$$X_{D,t} = \lambda_{D,t} Y_{D,t} mc_{D,t} T_{D,t} + \alpha_D \beta \left(\pi_{D,t+1}\right)^{\sigma} E_t\left\{X_{D,t+1}\right\} \tag{4.45}$$

$$Z_{D,t} = \lambda_{D,t} Y_{D,t} T_{D,t+k} + \alpha_D \beta \left(\pi_{D,t+1}\right)^{\sigma-1} E_t\left\{Z_{D,t+1}\right\} \tag{4.46}$$

Here, the reset domestic price inflation is defined as, $\overline{\pi}_{D,t} = \frac{\overline{P}_{D,t}}{P_{D,t-1}}$, and domestic price inflation is defined as, $\pi_{D,t} = \frac{P_{D,t}}{P_{D,t-1}}$. The real marginal cost for domestic firms in terms of domestic prices is given by, $mc_{D,t} = \frac{MC_{D,t}}{P_{D,t}}$. The law of motion for the domestic producer's prices in equation (4.42) can be written in terms of inflation as follows,

$$\pi_{D,t} = \left[\alpha_D + (1-\alpha_D)\left(\overline{\pi}_{D,t}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}. \tag{4.47}$$

Since labour is the only input into production, the nominal marginal cost for domestic firms, $MC_{D,t}$, can also be written as,

$$MC_{D,t} = \frac{W_{D,t}}{A_{D,t}}.$$

The real marginal cost for domestic firms, $mc_{D,t}$, in terms of domestic prices would then be,

$$mc_{D,t} = \frac{w_{D,t}}{A_{D,t}} \tag{4.48}$$

where $w_{D,t} = \frac{w_{D,t}}{P_{D,t}}$ are real wages in the domestic country.

The price-setting behavior of firms in the foreign country is similar to the price-setting behavior of firms in the domestic country, as described from equation $(4.40) - (4.63)$. In the foreign country, $(1 - \alpha_F)$ proportion of the firms reset their prices to $\overline{P}_{F,t}$ and the rest α_F proportion keep it the same as last year prices, $P^*_{F,t-1}$. Maximizing the current and future stream of profits by firms in the foreign country yields the following equation on reset foreign inflation, similar to equation (4.44)

$$\overline{\pi}_{F,t} = \frac{\sigma}{\sigma - 1} \pi^*_{F,t} \frac{X_{F,t}}{Z_{F,t}} \tag{4.49}$$

where $X_{F,t}$ and $Z_{F,t}$ are defined as follows,

$$X_{F,t} = \lambda_{F,t} Y_{F,t} mc_{F,t} T_{F,t} + \alpha_F \beta \left(\pi^*_{F,t+1}\right)^{\sigma} E_t \left\{X_{F,t+1}\right\} \tag{4.50}$$

$$Z_{F,t} = \lambda_{F,t} Y_{F,t} T_{F,t+k} + \alpha_F \beta \left(\pi^*_{F,t+1}\right)^{\sigma-1} E_t \left\{Z_{F,t+1}\right\} \tag{4.51}$$

Here the reset foreign price inflation is defined as, $\overline{\pi}_{F,t} = \frac{\overline{P}_{F,t}}{P^*_{F,t}}$, and the foreign price inflation is defined as, $\pi^*_{F,t} = \frac{P^*_{F,t}}{P^*_{F,t-1}}$. The real marginal cost for the foreign firms in terms of foreign prices is given by, $mc_{F,t} = \frac{MC_{F,t}}{P_{F,t}}$. The law of motion for the foreign producer's inflation is given by,

$$\pi^*_{F,t} = \left[\alpha_F + (1 - \alpha_F) \left(\overline{\pi}_{F,t}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}. \tag{4.52}$$

The real marginal cost for the foreign firms, $mc_{F,t}$, in terms of foreign prices would be,

$$mc_{F,t} = \frac{w_{F,t}}{A_{F,t}} \tag{4.53}$$

where $w_{F,t} = \frac{w_{F,t}}{P_{F,t}}$ denotes real wages in the foreign country.

The terms of trade equation (4.19) can be written as $T_t = \frac{X_t P^*_{F,t}}{P_{D,t}}$. Re-writing this gives us the following relation between the terms of trade, the nominal exchange rate change and producer price inflation between the two countries,

$$T_t = T_{t-1}\pi_{X,t}\frac{\pi^*_{F,t}}{\pi_{D,t}}. \tag{4.54}$$

Under a flexible price equilibrium, $\alpha_D = \alpha_F = 0$, such that all firms reset their prices in each period. This would imply, $P_{D,t} = \overline{P}_{D,t}$, $P^*_{F,t} = \overline{P}_{F,t}$ and $Disp_{D,t} = Disp_{F,t} = 1$. The reset price in each period would simply be a markup over marginal cost in both the countries i.e., $P_{D,t} = \frac{\sigma}{\sigma-1}MC_{D,t}$ and $P_{F,t} = \frac{\sigma}{\sigma-1}MC_{F,t}$.

4.2.3 Equilibrium

Aggregate goods market equilibrium in a small open economy

In this section we will describe the equilibrium for the benchmark case of the small open economy. To characterize the small open economy we follow Benigno and Paoli (2010) and limit $n \to 0$, such that $1 - \mu_D \to \chi$ and $\mu_F \to 0$ from equations (4.5) and (4.6). It can be seen that the share of domestic goods in the consumption basket of domestic households, μ_D, now depends only upon the degree of openness (inversely), while the share of domestic goods in the consumption basket of foreign households, μ_F, is negligible.[24] The real exchange rate in equation (4.17) is now given by,

$$Q_t = \frac{X_t P^*_{F,t}}{P_t} = \frac{P_{F,t}}{P_t} = T_{F,t} \tag{4.55}$$

(since $P^*_t = P^*_{F,t}$ under the limit $n \to 0$ in consumer price index equation (4.16)). The demand function equations (4.13) and (4.14) , aggregate demand equations (4.23) and

[24]Note that the negligible share of domestic goods in the foreign household's consumption basket does not mean that foreign households do not consume domestic goods. It just means that the size of the domestic country is small compared to the foreign country such that the share of the domestic good in it's basket appears to be negligible.

(4.25) , relative price and inflation relations in equations (4.20) and (4.21) reduce to the following,

$$
\begin{aligned}
C_{D,t} &= (1-\chi)\left(T_{D,t}\right)^{-\xi_D} C_t \quad ; \quad C_{F,t} = \chi \left(T_{F,t}\right)^{-\xi_D} C_t && (4.56)\\
C^*_{D,t} &= 0 \;\; ; \;\; C^*_{F,t} = \left(\frac{T_{F,t}}{Q_t}\right)^{-\xi_F} C^*_t && (4.57)\\
Y_{D,t} &= \left(T_{D,t}\right)^{-\xi_D}\left[(1-\chi) C_t + \chi Q_t^{\xi_F}\left(T_{D,t}\right)^{\xi_D-\xi_F} C^*_t\right] && (4.58)\\
Y_{F,t} &= C^*_t && (4.59)\\
T_{F,t} &= \left[\frac{1-(1-\chi)\left(T_{D,t}\right)^{1-\xi_D}}{\chi}\right]^{\frac{1}{1-\xi_D}} && (4.60)\\
\pi^*_t &= \pi^*_{F,t}, && (4.61)
\end{aligned}
$$

respectively.

Aggregate labour market equilibrium

Equilibrium in the labour market would require aggregate labour supply to be equal to aggregate labour demand. For the domestic country, labour is aggregated as follows,

$$H_{D,t} = \frac{1}{n}\int_0^n H_{D,t}(i)\, di$$

Using labour demand of a firm i, $H_{D,t}(i)$, from equation (4.37), and demand for the firms's output, $Y_{D,t}(i)$, from equation (4.22), we re-write equilibrium in labour market as,

$$H_{D,t} = \frac{Y_{D,t}}{A_{D,t}} Disp_{D,t} \tag{4.62}$$

where the price dispersion term, $Disp_{D,t} = \frac{1}{n}\int_0^n \left(\frac{P_{D,t}(i)}{P_{D,t}}\right)^{-\sigma} di$ and can be written recursively as,

$$Disp_{D,t} = \left(\pi_{D,t}\right)^{\sigma}\left[\alpha_D Disp_{D,t-1} + (1-\alpha_D)\left(\overline{\pi}_{D,t}\right)^{-\sigma}\right] \tag{4.63}$$

where $Disp_{D,t-1} = \frac{1}{n}\int\limits_{0}^{n}\left(\frac{P_{D,t-1}(i)}{P_{D,t-1}}\right)^{-\sigma} di$. Analogously, equilibrium in the foreign labour market implies,

$$H_{F,t} = \frac{Y_{F,t}}{A_{F,t}} Disp_{F,t} \tag{4.64}$$

where the price dispersion term, $Disp_{F,t} = \frac{1}{1-n}\int\limits_{n}^{1}\left(\frac{P^*_{F,t}(i)}{P^*_{F,t}}\right)^{-\sigma} di$, can be written recursively as,

$$Disp_{F,t} = \left(\pi^*_{F,t}\right)^{\sigma}\left[\alpha_F Disp_{F,t-1} + (1-\alpha_F)\left(\overline{\pi}_{F,t}\right)^{-\sigma}\right] \tag{4.65}$$

where $Disp_{F,t-1} = \frac{1}{1-n}\int\limits_{n}^{1}\left(\frac{P^*_{F,t-1}(i)}{P^*_{F,t-1}}\right)^{-\sigma} di$. For a given wages and prices, labour supply equations (4.31) and (4.32) along with labour demand equations (4.62) and (4.64) determines the labour market equilibrium.

Trade balance

The trade balance is captured through net exports (net trade of goods) in domestic and foreign country. The value of net exports for the domestic country in terms of domestic consumer prices, $NX_{D,t}$, is defined as the value of total imports (in domestic consumer prices) subtracted from the value of total exports (in domestic consumer prices), and is given by,

$$\begin{aligned} NX_{D,t} &= \frac{P_{D,t}C^*_{D,t}}{P_t} - \frac{P_{F,t}C_{F,t}}{P_t} \\ &= T_{D,t}C^*_{D,t} - T_{F,t}C_{F,t} \end{aligned} \tag{4.66}$$

Similarly, the value of net exports for the foreign country in terms of foreign consumer prices (foreign currency), $NX_{F,t}$, is defined as the value of total imports (in foreign consumer prices) subtracted from the value of total exports (in foreign consumer prices), and is given by

$$NX_{F,t} = \frac{P^*_{F,t}C_{F,t}}{P^*_t} - \frac{P^*_{D,t}C^*_{D,t}}{P^*_t}$$

$$= \frac{T_{F,t}}{Q_t}C_{F,t} - \frac{T_{D,t}}{Q_t}C^*_{D,t} \quad (4.67)$$

A positive and a negative net exports are referred to as trade surplus and trade deficit, respectively.

4.2.4 Welfare losses

The utility based welfare criterion defines welfare as an expected lifetime utility of a representative household (see Chapter-6, Woodford (2003)).[25] The welfare function in the domestic country would thus be a following lifetime utility of a representative domestic household, described in equation (4.1):

$$Welfare_{D,t} = E_t \sum_{t=0}^{\infty} \beta^t U_{D,t}$$

where, $U_{D,t} = U\left(C_t, H_{D,t}\right) = \frac{(C_t)^{1-\nu_D}}{1-\nu_D} - \omega_D \frac{\left(H_{D,t}\right)^{1+\eta_D}}{1+\eta_D}$. We can write the above welfare function recursively as:

$$Welfare_{D,t} = U_{D,t} + \beta E_t \left\{Welfare_{D,t+1}\right\} \quad (4.68)$$

Similarly the welfare function in the foreign country would be a lifetime utility of a representative foreign household, described in equation (4.3). Writing welfare function

[25]We do not take an approximation of the welfare function in this chapter as we are solving a non-linear model. The welfare described in this section would be used later to compare alternate monetary policy rules.

recursively we get,

$$Welfare_{F,t+1} = U_{F,t} + \beta E_t \left\{ Welfare_{F,t+1} \right\} \tag{4.69}$$

where, $U_{F,t} = U\left(C_t, H_{F,t}\right) = \frac{(C_t)^{1-\nu_F}}{1-\nu_F} - \omega_F \frac{\left(H_{F,t}\right)^{1+\eta_F}}{1+\eta_F}$. We define welfare losses in the domestic country and foreign country as $-Welfare_{D,t}$ and $-Welfare_{F,t}$, respectively.

4.2.5 Monetary Policy Rules

Simple Taylor rule: benchmark policy

In the benchmark case we assume that the central banks in both the domestic and the foreign country set a monetary policy rule on the nominal interest rates using a simple Taylor rule (see Taylor (1993)). Here the central bank attempts to stabilize both inflation and output. In this case, we assume that the measure of inflation a central bank targets is the consumer price inflation in their respective countries. The rules are given by,

$$\text{TR-CPI} \quad : \quad (1+R_t) = \overline{R} \left(\frac{\pi_t}{\overline{\pi}}\right)^{\phi_\pi} \left(\frac{Y_{D,t}}{Y_{D,t}^{fp}}\right)^{\phi_y} \tag{4.70}$$

$$\text{TR-CPI} \quad : \quad (1+R_t^*) = \overline{R}^* \left(\frac{\pi_t^*}{\overline{\pi}^*}\right)^{\phi_\pi^*} \left(\frac{Y_{F,t}}{Y_{F,t}^{fp}}\right)^{\phi_y^*} \tag{4.71}$$

for the domestic and foreign country, respectively. Here, $\overline{R} = \frac{1}{\beta}$ and $\overline{R}^* = \frac{1}{\beta}$ are the steady state values of nominal interest rate, R_t, and R_t^*, respectively. We get these steady state values from Euler equations (4.29) and (4.30) . Here, $\overline{\pi}$ and $\overline{\pi}^*$ are the steady state values of consumer price inflation, and $Y_{D,t}^{fp}$ and $Y_{F,t}^{fp}$ are the flexible price equilibrium levels of output, in the domestic and foreign country, respectively. The parameters $\left(\phi_\pi,\ \phi_y\right)$ and $\left(\phi_\pi^*,\ \phi_y^*\right)$ capture the responsiveness of the interest rates to the deviation of inflation from its steady state level and deviation of output from its flexible price level counterpart in the respective countries.

Alternate monetary policy rules

For comparative analysis, we only vary the monetary policy rule in the domestic economy/ SOE. The monetary policy rule for the foreign economy is assumed to be a simple Taylor rule as described in equation (4.71) for all the alternative monetary policy cases we consider for the domestic economy.

The Taylor rule we consider in the benchmark model, as described in equation (4.70) is a consumer price inflation (CPI) based rule. The first alternate rule we consider is a Taylor rule with producer's price index (PPI), given by,

$$\text{TR-PPI: } (1+R_t) = \overline{R}\left(\frac{\pi_{D,t}}{\overline{\pi}_D}\right)^{\phi_\pi}\left(\frac{Y_{D,t}}{Y_{D,t}^{fp}}\right)^{\phi_y} \tag{4.72}$$

Here, $\pi_{D,t}$ is producer price inflation in the domestic country and $\overline{\pi}_D$ is it's steady state value. This is an interesting case because it has been shown in Gali and Monacelli (2005) that under a flexible exchange regime it is optimal for the central bank of a small open economy to target producer price inflation. Later, Engel (2011) shows that under local currency pricing, exchange rate flexibility does not matter and the optimal policy for a central bank is to completely stabilize consumer price inflation.[26]

It has been argued in Calvo and Reinhart (2002) and Reinhart (2000) that emerging market economies use their foreign exchange reserves and monetary policy with interest rates as an instrument to stabilize exchange rate movements in a flexible exchange rate regime. There also exists empirical evidence showing that central banks in emerging markets consider exchange rate movements while setting their monetary policy (see Cuevas and Topak (2008), Aizenman et al. (2011)). Given this, the next set of rules we consider

[26]These papers analyze shocks to first moment, while we consider shocks to second moments of the underlying process.

are Taylor rules (both CPI and PPI) with nominal exchange rates, as given by

$$\text{TR-CPI-ER:} \qquad (1+R_t) = \overline{R}\left(\frac{\pi_t}{\overline{\pi}}\right)^{\phi_\pi}\left(\frac{Y_{D,t}}{Y_{D,t}^{fp}}\right)^{\phi_y}\left(\frac{X_t}{X_{t-1}}\right)^{\phi_X} \tag{4.73}$$

$$\text{TR-PPI-ER} \quad : \quad (1+R_t) = \overline{R}\left(\frac{\pi_{D,t}}{\overline{\pi}_D}\right)^{\phi_\pi}\left(\frac{Y_{D,t}}{Y_{D,t}^{fp}}\right)^{\phi_y}\left(\frac{X_t}{X_{t-1}}\right)^{\phi_X} \tag{4.74}$$

Here, $\frac{X_t}{X_{t-1}}$ denotes a change in the nominal exchange rate and the policy rate responds positively to a positive change in the nominal exchange rate. This is because a depreciation of currency would imply an increase in expected future inflation (due to a rise in import prices) and an increase in output (because of a higher demand for exports and import substitution). A rise in the interest rate is thus required to stabilize the economy from the effects of the depreciation.[27]

From the empirical evidence shown in Section 4.1.1, it is evident that the movement of the exchange rates (both nominal as well as real) is high and significant in emerging markets with uncertainty shocks. We also observed that the nominal interest rates increase as a response to an increase in global uncertainty and thus can reinforce the adverse effects of uncertainty shock. At the same time the interest rates do not seem to stabilize exchange rates. Aizenman et al. (2011) also show that when monetary policy is geared to stabilize inflation, output and exchange rates, exchange rates are not much stabilized as a part of mixed strategy in an IT (Inflation Targeting) regime. Given the inability of interest rate rules to absorb the effect of the shock under consideration, we examine, an alternative instrument for conducting monetary policy, namely, exchange rates. This puts a rule on exchange rates directly and does not let them float freely. These set of rules are called exchange rate rules (ERR) where a central bank manages exchange rates to target inflation and output. The Monetary Authority of Singapore (MAS) has been following this rule since 1981 (McCallum (2006)). We consider a simple

[27]The rule would suggest a fall in the nominal interest rates in case of an appreciation.

exchange rate rule as described in Heiperzt et al. (2017),

$$\text{ERR: } \frac{X_t}{X_{t-1}} = \left(\frac{Y_{D,t}}{Y_{D,t}^{fp}}\right)^{-\phi_y^e} \left(\frac{\pi_t}{\overline{\pi}}\right)^{-\phi_\pi^e} \tag{4.75}$$

Here, ϕ_y^e and ϕ_π^e are the response parameters of nominal exchange to the change in output and inflation. Note that the exchange rate responds negatively to an increase in inflation and output to stabilize the economy. This is because increase in inflation and output can be stabilized when nominal exchange rates fall (an appreciation). An appreciation reduces inflation (by reducing the price of imports) and also reduces output (by reducing the foreign demand for domestic goods and reducing the domestic good's demand by domestic households). We also consider an extreme case of a fixed exchange rule (PEG) where the central bank completely stabilizes the nominal exchange rate, as given by

$$\text{PEG: } \frac{X_t}{X_{t-1}} = 1 \tag{4.76}$$

When, $\phi_y^e \rightarrow 0$ and $\phi_\pi^e \rightarrow 0$, the exchange rate rule (4.75) approaches a PEG rule in (4.76). As values of ϕ_y^e and ϕ_π^e increase, the exchange rate adjusts more to stabilize the economy. Note that interest rates are endogenously determined in the economy under ERR and PEG rule.

4.2.6 Exogenous shock processes

The technology process for domestic country firms, $A_{D,t}$, in equation (4.37), follows a standard AR(1), as given by,

$$A_{D,t} = (1 - \rho_D)\,\overline{A}_D + \rho_D A_{D,t-1} + \epsilon_{D,t} \tag{4.77}$$

where $\epsilon_{D,t}$ is a shock to the first moment of the technology process. For the present analysis we assume that there are no shocks to technology in the domestic economy, such that the technology $A_{D,t}$ is at its steady state level $\overline{A}_D$. Since we are interested in global uncertainty shocks we assume a shock to the second moment of a foreign country's preference/ demand and technology/ productivity process. We follow Basu and Bundick (2017) and Fernández-Villaverde et al. (2011) to describe the shock processes with uncertainty shocks. The demand shock process in equation (4.3) and productivity shock processes in equation (4.37) and (4.38) take the following form,

$$\Gamma_{F,t} = (1-\delta_F)\,\overline{\Gamma}_F + \delta_F \Gamma_{F,t-1} + v_{F,t-1}\varepsilon_{F,t} \tag{4.78}$$

$$A_{F,t} = (1-\rho_F)\,\overline{A}_F + \rho_F A_{F,t-1} + u_{F,t-1}\epsilon_{F,t} \tag{4.79}$$

where $\varepsilon_{F,t}$ and $\epsilon_{F,t}$ are shocks to the first moment of demand and productivity levels. The standard deviations $v_{F,t-1}$ and $u_{F,t-1}$ in the foreign demand and productivity shocks are not constant and are described by the following AR(1) processes,

$$v_{F,t} = (1-\delta_{\sigma_F})\,\overline{v}_F + \delta_{\sigma_F} v_{F,t-1} + \varpi_F \vartheta_{F,t} \tag{4.80}$$

$$u_{F,t} = \left(1-\rho_{\sigma_F}\right)\overline{u}_F + \rho_{\sigma_F} u_{F,t-1} + \varkappa_F \zeta_{F,t}. \tag{4.81}$$

Here, $\vartheta_{F,t}$ and $\zeta_{F,t}$ are shocks to the second moment or an uncertainty shock to the underlying demand and the productivity levels, respectively. In other words, uncertainty shocks here refer to the shocks to standard deviation of the underlying process. It is assumed that the stochastic shocks, $\varepsilon_{F,t}$, $\epsilon_{D,t}$, $\epsilon_{F,t}$, $\vartheta_{F,t}$ and $\zeta_{F,t}$, are independent and normally distributed random variables. In the baseline calibration we show results for uncertainty shocks to the demand process. The results for the uncertain productivity shocks are very similar. Also, $\overline{A}_D = \overline{A}_F = 1$, at the steady state.

4.2.7 Solution method

We are interested in looking at the effects of shocks to the second moments (or uncertainty shocks) of the demand/ preference levels of the foreign country on a small open economy (domestic country). To capture the complete effect of the second moment shocks on the endogenous variables of the model we need to take the third order approximation of the model equations as explained in Fernández-Villaverde et al. (2011) and later also applied in Basu and Bundick (2017). Following this, we do a third order Taylor series approximation of the model using the Dynare software package in MATLAB to find a solution to our benchmark model.[28] All the approximations are done around the stochastic steady state.

4.2.8 Calibration

We calibrate the small open economy to a prototypical emerging market economy and the foreign country, which comprises the world, to an advanced economy. We estimate the degree of openness parameter, χ, to be 0.6, as the average trade share to GDP of emerging market economies. To get this we use World Bank's country level trade data for year 2015.[29] The value of κ, which is the initial parameter in the asset market condition is estimated to be 3.8. We calculate this using the OECD database on national accounts.[30] Details on the calculation of χ and κ is provided in the Data Appendix C.1. The inverse of the intertemporal elasticity of substitution parameter, ν_D and ν_F for the domestic and the foreign country, respectively, are set to 5 following Fernández-Villaverde et al. (2011) and Benigno et al. (2012). We make the domestic goods and foreign goods relatively substitutable in the benchmark calibration for both the countries, thus setting the value of the elasticity of substitution between domestic and foreign goods, ξ_D and ξ_F, to be 1.5 as calculated in Benigno et al. (2012). The discount factor, β is assumed to be the same in both the countries and is set to 0.994 following Basu and Bundick (2017). The utility parameter, ω_D and ω_F capturing the weight given to the household's disutility from the labour supply is set to 1 using Fernández-Villaverde et al. (2011). The parameter for the elasticity of substitution between varieties, θ, is set to 6 following Benigno et al. (2012)

[28] We use MATLAB 2015 and Dynare 4.4.3 for calibrating the model.
[29] The data was accessed in November, 2018 from:
https://datacatalog.worldbank.org/search?sort_by=title&sort_order=ASC
[30] Data is accessed in January, 2019 from OECD: https://stats.oecd.org/#

such that the steady state markup for a firm is 20 per cent. In the baseline calibration we fix the value of stickiness parameter for the foreign country, α_F, to be 0.66 following Sbordone (2002) and Gali et al. (2001). These papers provide empirical evidence for stickiness parameter for the US and Europe, respectively. For the domestic country, the parameter for stickiness, α_D is set slightly higher to 0.75 such that domestic firms revise prices in 4 quarters.[31] We also compare our baseline sticky price calibration results to a completely flexible price calibration, where $\alpha_D = 0$ and $\alpha_F = 0$. The value of the inverse of the Frisch elasticity of substitution (IFES) varies from 0.5 to 1000 in the literature (see Basu and Bundick (2017), Fernández-Villaverde et al. (2011)). Here we set IFES, η_D, for domestic households to 25 and IFES, η_F, for foreign households to 50.[32] The preference shock parameters for the preference shock (both first moment and second moment), for the foreign country are calibrated from Basu and Bundick (2017), and are set as follows: $\delta_F = 0.94$, $\delta_{\sigma_F} = 0.74$. The steady state values for the demand shock, $\overline{\Gamma}_F$, and its standard deviation, $\overline{\upsilon}_F$, are set to 1 and 0.085 respectively. The scaling parameter for the uncertainty shock ϖ, is set to 0.18 following Benigno et al. (2012).

For the baseline calibration of the Taylor rule as described in equations (4.70) and (4.71), for both the countries, we set the weight on inflation to be, $\phi_\pi = \phi_\pi^* = 1.5$ and the weight on output to be, $\phi_y = \phi_y^* = 0.5$. These are the standard values used in the literature (see Taylor (1993)). We also consider models with alternate monetary policies. The parameter for Taylor rules with an exchange rate where weight on the exchange rate change, ϕ_X, is set to 0.05 uses estimates from Cuevas and Topak (2008). The exchange rate rule parameters, ϕ_π^e, i.e., weight on the inflation gap, and ϕ_y^e, i.e., weight on the output gap are set to 0.16 and 0.04 following estimates from Parrado (2004) and Heiperzt et al. (2017). We also calculate the second moments of the simulated data from the model by varying the value of ϕ_X to 0.2 and 0.5, and of ϕ_π^e to 0.3 and 0.8. The parameters are summarized in Table 4.1 below.

[31] See Devereux and Engel (2003).

[32] We choose the minimum values for the IFES such that the impulse responses are matched qualitatively.

4.3 Impulse Response Functions

4.3.1 Effects of an uncertainty shock to the foreign demand

In this section we discuss the macroeconomic effects of a one standard deviation shock to uncertainty in demand of the foreign households as described in equation (4.80) .

[INSERT FIGURE 4-6]

Figure 4-6 shows the impulse responses of the macroeconomic variables for the domestic economy/ SOE when the foreign/ world economy experiences an uncertainty shock to its demand. As described in Basu and Bundick (2017) the uncertainty shock to demand contracts the economy as agents save more (precautionary savings) and consume less today. Ravn and Sterk (2017) argues that a higher risk of job loss and worsening job finding prospects during unemployment depress consumption goods demand today because of a precautionary savings motive. Note that both the domestic as well as foreign economy have a new-Keynesian feature of nominal rigidities in the form of price stickiness and thus output is demand determined. When an uncertainty shock hits the foreign economy the households save more and consume less today which leads to a fall in aggregate demand and hence prices in the foreign economy. When a SOE (domestic) is connected to the world through trade of goods and assets, the exogenous uncertainty shock to foreign demand also affects them.

Parameter	Notation	Value	Source
Households & Firms			
Discount factor	β	0.994	Basu and Bundick (2017)
Inverse of intertemporal elasticity of substitution	ν_D ; ν_F	5 ; 5	Fernández-Villaverde et al. (2011)
Inverse of Frisch elasticity of substitution	η_D ; η_F	25 ; 50	Author
Stickiness parameter	α_D ; α_F	0.75 ; 0.66	Author; Sbordone (2002)
General			
Degree of openness	χ	0.6	Author
Elas. of substitution between domestic and foreign goods	ξ_D ; ξ_F	1.5 ; 1.5	Benigno et al. (2012)
Elas. of substitution between varieties	θ	6	Benigno et al. (2012)
Shocks: preference shock			
Level parameters	δ_F ; $\overline{\Gamma}$	0.94 ; 1	Basu and Bundick (2017)
Uncertain shock parameters	δ_{σ_F},$\overline{\upsilon}$	0.74 ; 0.085	Basu and Bundick (2017)
	ϖ	0.18	Benigno et al. (2012)
Policy : Taylor rule coefficients			
Inflation	ϕ_π ; ϕ_π^*	1.5 ; 1.5	Taylor (1993)
Output gap	ϕ_y ; ϕ_y^*	0.5 ; 0.5	Taylor (1993)
Exchange rate change	ϕ_X	0.05	Cuevas and Topak (2008)
Policy: Exchange rate rule coefficients			
Inflation	ϕ_π^e	0.16	Parrado (2004)
Output gap	ϕ_y^e	0.04	Parrado (2004)

Table 4.1: Summary of parameter values

The domestic country experiences a sudden outflow of capital and its nominal currency depreciates. Subplot (2,1) of Figure 4-6 shows the depreciation of the nominal exchange rate. Since prices are sticky in both the countries, the REER also depreciates following a nominal exchange rate depreciation (Subplot (2,2)). This result is consistent with Fact 3 we observe in the data. Due to an uncertain future demand, households in the domestic economy too save more (precautionary savings) and consume less today because of which consumption demand falls (Subplot (1,1)). Net exports rise due a fall in imports as a result of a depreciation (Subplot (1,2)).[33] This result is in line with empirical Facts 1 and 2, although in the data we observe the trade balance improves only after two quarters. The consumption basket in the SOE has a share of imported goods proportional to the degree of openness as shown in equation (4.56.2). Due to a depreciation of the currency, the import prices of the foreign goods consumed by domestic households increases. This increases the consumer price inflation in the domestic economy (Subplot (3,2)). Since the central bank follows a simple interest rate rule described in equation (4.70) , the nominal interest rate also rises to stabilize consumer price inflation in the domestic country.[34] This result too qualitatively matches empirical Fact 4 we observe in the data. The welfare losses in the domestic economy are positive because of the real effects of the shock. To summarize, the calibration results from the model fit well qualitatively with the empirical stylized facts.

[INSERT FIGURE 4-7]

Figure 4-7 compares the impulse responses for uncertainty shocks to foreign demand under a flexible price allocation (red line) with the sticky price allocation (blue line). The calibration under flexible price allocation is interesting because it can affect the way real variables respond to the uncertainty shock. It has been shown in Basu and Bundick (2017), that a standard model with flexible prices does not generate a negative comovement in uncertainty and real demand in the economy as observed in the data, which nominal rigidities in the form of sticky prices are able to generate. Figure 4-7 shows that only nominal variables change as a response to an increase in the uncertainty and

[33] The initial value for the net exports is negative here such that the country starts with a trade deficit.

[34] Note that the output gap would be negative here which would require the central bank to reduce the nominal interest rates but the net change depends on the Taylor parameters and the size of the change in inflation and output.

none of the real variables are affected under a flexible price allocation. This happens because the economy under flexible price equilibrium is supply determined and not demand determined. When savings increase due to an uncertainty shock the supply side of the economy is unaffected as the savings in the present model are not investible (no capital in the model). This is in contrast to Basu and Bundick (2017) where a flexible price allocation results in the expansion of economy with an uncertainty shock. This happens because they assume a model with capital such that when savings increase, investment increases in the economy, leading to a capital driven expansion of output. Since we consider a model without capital, this channel does not exist. The nominal variables, price level and the nominal interest rate, adjusts here as can be seen in Subplot (3,1) and (3,2) respectively. This happens because savings (in assets) have a tendency to go out of the country which reduces the price of an asset in the domestic country and thus increases the nominal rate of interest. To satisfy the Taylor rule, we would observe that consumer prices also rise with increasing nominal interest rates. Moreover, increasing consumer prices also ensures that the real savings and the real interest rate do not show much change in the new equilibrium.

4.3.2 Role of monetary policy

In the model calibration so far we have assumed that the central bank of a small open economy (domestic country) follows a simple Taylor rule (TR-CPI) described in equation (4.70) . As discussed earlier a positive response of the interest rate rule in the EMEs amplifies the contractionary effect of an uncertainty shock on the real economy. In this section we consider alternate monetary policy rules to ascertain the role of monetary policy in determining the post shock (uncertainty shock) equilibrium. For comparative analysis we set TR-CPI as the benchmark case. The other monetary policy rules we consider for comparison can broadly be grouped into two categories. The first category correspond to modified Taylor rules. Here we consider a simple Taylor rule with PPI (TR-PPI), a CPI Taylor rule with an exchange rate mandate (TR-CPI-ER), a PPI Taylor rule with an exchange rate mandate (TR-CPI-ER), as specified in equations (4.72), (4.73) and (4.74), respectively. In all the above mentioned cases, we have free movement of assets across countries and an independent monetary policy. Following the impossible trinity, the exchange rate is completely flexible.

The second category is a different class of monetary policy rules, where the exchange rate is the monetary policy instrument. Here we consider a very simple exchange rate rule (ERR) and an extreme case of fixed exchange rates (PEG), as specified in equations (4.75) and (4.76), respectively. A detailed description of the alternate monetary policy rules is given in Section 4.2.5.

[INSERT FIGURES 4-8, 4-9 and 4-10]

Figure 4-8 compares the impulse response functions for welfare losses for the above described monetary policy rules. As can be seen, welfare losses do not vary significantly among modified Taylor rules (TR-CPI, TR-PPI, TR-CPI-ER and TR-PPI-ER) and the PEG rule, for the given calibration. Flexible exchange rate regimes and fixed exchange rate regimes give very similar welfare losses with the present calibration. We do find however that the PEG rule does slightly better (not significantly) than interest rate rules. On impact, exchange rate rules reduce welfare losses by 21 per cent, when the inflation parameter in exchange rate rule, ϕ_{π}^{e}, is 0.8.[35] The reduction in welfare losses is 9 per cent and 13 per cent when ϕ_{π}^{e} equals 0.16 and 0.30, respectively. This happens because in the presence of uncertainty, with the central bank following an interest rate rule (flexible exchange rates), the movement in exchange rates are primarily driven by a *hedging motive* (see Benigno et al. (2012)). Thus the link between exchange rate and the monetary policy through interest rates (UIP condition) breaks down with higher-order moment shocks. When the link between monetary policy (through interest rate rules) and exchange rate breaks down, the monetary policy becomes ineffective in stabilizing

[35]The comparisons are made from the benchmark policy.

the economy via stabilizing exchange rates. Due to this, we observe higher welfare losses when monetary policy is implemented with interest rate rules as an instrument.

Exchange rate rules give the least welfare losses as they are associated with lower risk premiums. Figure 4-9 above compares the risk premiums under different monetary policy rules.[36] The risk premiums with exchange rate rules are strictly lower than the considered Taylor rules and the PEG rule. In particular, the risk premiums reduce by 45 per cent, 61 per cent and 91 per cent from the benchmark rule when ϕ_{π}^{e} equals 0.16, 0.30 and 0.80, respectively, in an ERR. This result is consistent with Heiperzt et al. (2017), who show that ERRs are associated with lower risk premiums than interest rate rules. The risk premiums are lower with ERRs because movements in exchange rate are no longer guided by a *hedging motive*, but rather by a rule as shown in the equation (4.75). This restores the broken link between monetary policy, exchange rates and other real variables in the domestic economy like inflation and output. Subplot (3,1) in Figure 4-10 shows that the output fall is the least in ERR vis-a-vis other rules considered. This happens because ERRs are associated with lower risk premiums and thus lead to a lower precautionary motive to save. Thus the adverse impact on aggregate demand triggered by an uncertainty shock in a demand determined economy is weakened when monetary policy follows an exchange rate rule. Consumer price inflation is negative as the currency does not depreciate much and PPI falls in the domestic country (due to fall in the demand). Under ERR, an initial depreciation of the currency with an expectation of future currency appreciation leads to an increased demand for bonds denominated in the home currency. This increases the price of bonds, which leads to a fall in nominal interest rates.

On the other extreme, the fixed exchange rate regime will not generate any movement in the exchange rates or the risk premiums when the economy is hit with uncertainty shocks. This implies that other nominal variable like consumer price inflation and nominal

[36]The risk premiums plotted here are levels and not logs. Values less than 1 here signify negative log risk premiums, rp_t.

interest rate adjusts more to stabilize the economy, as shown in Figure 4-10. Subplot (2,1) in Figure 4-10 shows that the movement of consumer price inflation under PEG rule is the highest compared to other rules. Moreover, output fluctuates less under PEG than in interest rate rules considered (see Subplot (3,1)). Due to this balanced trade-off between inflation and output stabilization, we get similar welfare losses with a PEG rule and interest rate rules. Among the interest rate rules, Taylor rules with CPI as inflation measure performs the worse. Although the welfare losses are similar among Taylor rules, the nominal exchange rate movements with TR-CPI and TR-CPI-ER are very high. In fact it is highest in the benchmark case of TR-CPI (see Subplot (1,1)). This is consistent with the literature which shows that with producer currency pricing, a Taylor rule with CPI brings more inefficiency (see Gali and Monacelli (2005), Engel (2011), Devereux and Engel (2003)). Taylor rules with an exchange rate mandate perform slightly better than those without it but they do not significantly reduce welfare losses.

[INSERT TABLE 4.2]

We investigate the response of the economy under different monetary policy rules to further examine how the economy responds in the long run. We simulate data from the model for 100 periods (25 years) under the considered monetary policy rules.[37] Table 4.2 compares the standard deviation of some important variables under different monetary policy rules. The ERR (column 5) outperforms all monetary policy rules and gives strictly lower standard deviation of all variables. The standard deviation of the nominal exchange rate, output and CPI is reduced by 85 per cent, 36 per cent and 45 per cent respectively from the benchmark case (column 1). The PEG rule (column 6) stands out as the second best monetary policy rule with the fall in the standard deviation of output, inflation and nominal exchange rates upto 13 per cent, 37 per cent and 100 per cent, respectively. Among Taylor type interest rate rules, TR-PPI-ER does the best. This is consistent with the results shown in Cook (2004) where, he argues that the fixed exchange rate

[37]The economy is assumed to be at the steady state in the initial period.

regimes offer greater stability than interest rate rules. The ranking of monetary policy rules based on second moments is consistent with the impulse response for welfare losses discussed above.

[INSERT TABLE 4.3 and FIGURE 4-11]

Table 4.3 compares the Taylor rules with an exchange rate mandate with varying degrees of the exchange rate parameter (ϕ_X), and exchange rate rules with varying degree of the inflation parameter (ϕ_π^e). Among the Taylor rules (column 1-6), TR-PPI-ER with $\phi_X = 0.5$, gives the least standard deviations of the variables. However, ERR with the lowest value of $\phi_\pi^e = 0.16$, performs better than TR-PPI-ER with ϕ_X as high as 0.5. When the response parameter of the exchange rates to inflation, ϕ_π^e, increases, both output and inflation are stabilized more at the cost of increasing variability in nominal exchange rates. When the inflation parameter, ϕ_π^e, increases from 0.16 to 0.30, the standard deviation of output and inflation reduces by 21 per cent and 11 per cent respectively, but the exchange rate variability is increased by 75 per cent. In an extreme case, the nominal exchange rate variability increases by 248 per cent when the inflation parameter is increased from 0.16 to 0.80. Note that even with ϕ_π^e as high as 0.8, the variability of the nominal exchange rate is much lower compared to Taylor interest rate rules.

To summarize, there exists a trade-off between stabilizing the nominal exchange rate and inflation-output with exchange rate rules. The choice of ϕ_π^e by a central bank should thus depend on the weight it puts on variability of the nominal exchange rates and the inflation in its objective function. Furthermore, the trade off can be noticed in Figure 4-11, in Subplots (1,1), (2,1), (3,1) corresponding to the nominal exchange rate, consumer price inflation and output, respectively. Welfare losses reduce by 14 per cent when ϕ_π^e increases from 0.16 to 0.80 due to more stabilized consumer price inflation and output. The higher value of ϕ_π^e ensures that exchange rates respond more to the change in key fundamental variables governing the domestic economy.

4.4 Conclusion

This chapter explores the role of exchange rates (both nominal and real) and monetary policy in amplifying/ stabilizing the real effects of global uncertainty shocks in a small open economy. Using a local projection method, we produce stylized facts from the data to examine effects of an increase in global uncertainty on macroeconomic variables of EMEs. We consider six EMEs (Brazil, Mexico, Indonesia, India, Russia and South Africa) and six advanced economies (US, UK, Australia, Canada, Japan and Korea) for our analysis. We build a small open economy NK-DSGE model to qualitatively fit the stylized facts from the data and compare responses of an economy with alternate monetary policy rules. To the best of our knowledge this is the first paper analyzing the effects of an uncertainty shock in a small open economy NK-DSGE model. The small open economy is calibrated to a prototypical EME. We observe that an increase in global uncertainty depreciates the currency in EMEs, as capital moves out of these economies. Due to a precautionary motive to save, households save more and consume less. As argued in the literature, nominal and real depreciation of exchange rates lead to a worsening of the balance sheets of firms, and foreign investors pull out funds from the domestic economy, which further depreciates the currency. Since the world economy also slows down due to global uncertainty shocks, the depreciated currency does not produce an increase in the demand for domestic goods. Thus, exchange rate movements in EMEs amplify the real effects of uncertainty shocks on these economies. The currency depreciation also leads to an increase in the consumer price inflation in the EMEs. A central bank following an interest rate rule (simple Taylor rule) with an inflation stabilization mandate, thus increases the nominal interest rate. Both nominal exchange rates and monetary policy based on interest rate rules thus amplify the real effect of an uncertainty shock. The stabilization of the exchange is very important to stabilize the small open economy faced with a global uncertainty shock and interest rate rules are ineffective in doing so. This happens because, UIP fails and the link between monetary policy (interest rate rules), exchange rates and crucial macroeconomic variables of domestic economy like inflation and output breaks down under uncertainty shocks. This generates time varying risk premiums under interest rate rules.

Welfare losses are distinctly lower when monetary policy follows exchange rates as an instrument instead on nominal interest rates. To be specific, welfare losses reduce by 21 per cent with exchange rates rules. The second order moments from the model show that the variability of nominal exchange rates, output and CPI is reduced by 85 per cent, 36 per cent and 45 per cent, respectively, when exchange rate rules are followed instead of interest rate rules. Exchange rate rules have a stabilizing effect on the economy because under these rules exchange rates are guided by a domestic country's macroeconomic factors and not by a hedging motive. Alternately, exchange rate rules are associated with a lower risk premium which reduces the real effect of uncertainty shocks on the domestic economy.

The current model framework does not feature some of the frictions standard in the literature (like imperfections in domestic financial markets or transactions costs) typical of an EME. For future research, we believe that adding the following features to the model can make the framework richer: (1) Adding trend inflation rate to a small open economy (EME). This would allow us to analyse the case of a zero lower bound (ZLB) in the foreign economy (AE) leaving the domestic economy (EME) unconstrained (i.e. no ZLB). (2) Introducing foreign borrowing by domestic firms as working capital loans. This way external debt in major currencies can be introduced.

Figures

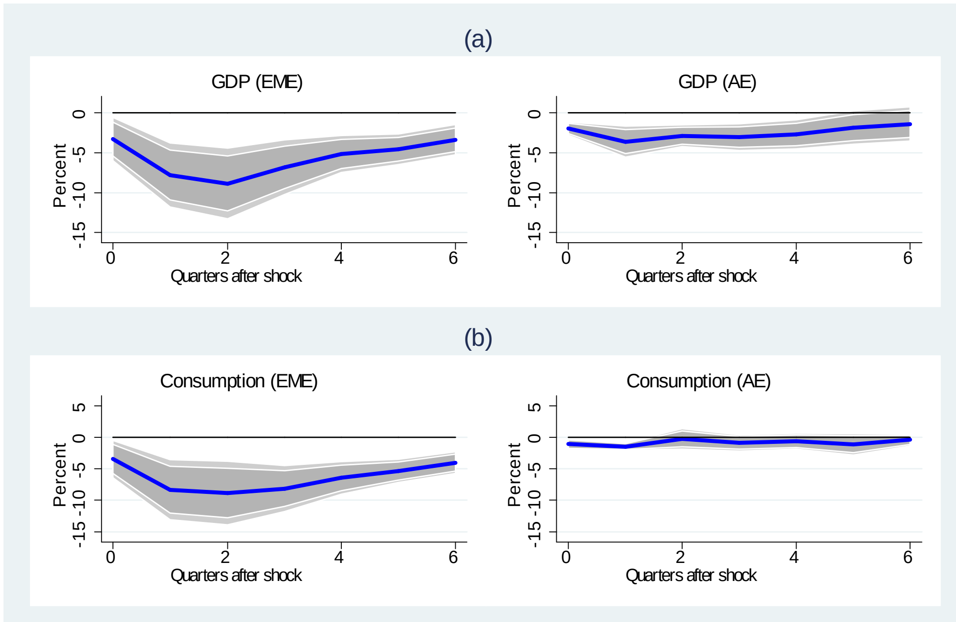

Figure 4-2: Local projection responses for (a) GDP; (b) Consumption with VXO impulse

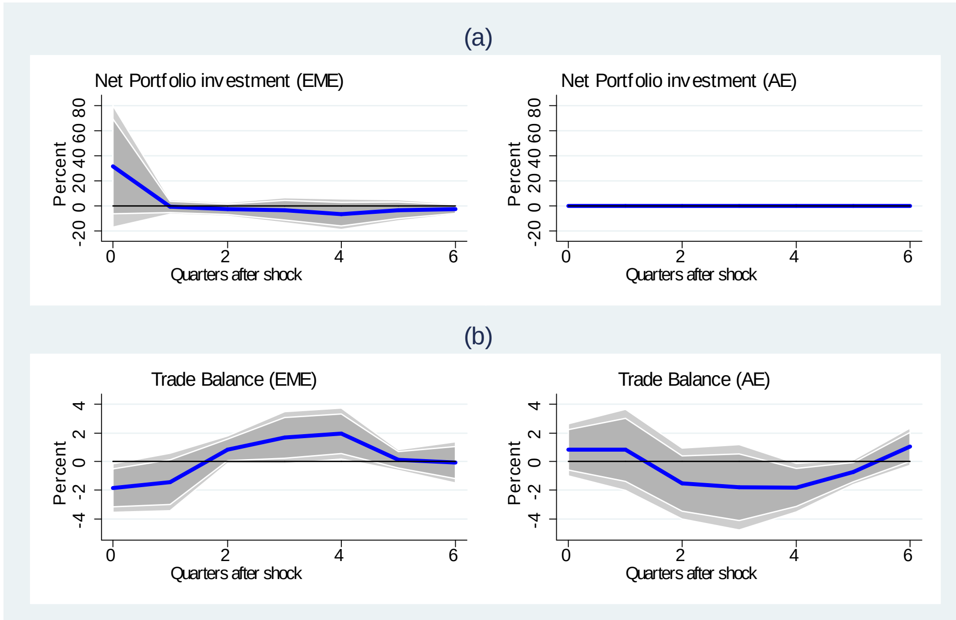

Figure 4-3: Local projection responses for (a) Net portfolio investment; (b) Trade balance with VXO impulse

Variable	Standard deviation×100					
	TR-CPI	TR-PPI	TR-CPI-ER	TR-PPI-ER	ERR	PEG
			ϕ_X=0.05	ϕ_X=0.05	ϕ_π^e=0.16	
	(1)	(2)	(3)	(4)	(5)	(6)
Consumption	2.484	2.483	2.484	2.483	2.476	2.484
Output	2.502	2.471	2.473	2.446	1.602	2.182
Net exports	1.450	1.451	1.450	1.451	1.455	1.450
Inflation (PPI)	3.081	3.041	2.940	2.914	1.673	1.911
Inflation (CPI)	3.057	3.064	2.923	2.943	1.695	1.933
Nominal ER	1.656	1.607	1.478	1.449	0.246	000
REER	0.561	0.550	0.561	0.511	0.507	0.109
Interest rates	3.689	3.711	3.584	3.614	2.645	2.877

Table 4.2: Comparing second empirical moments for different monetary policy rules

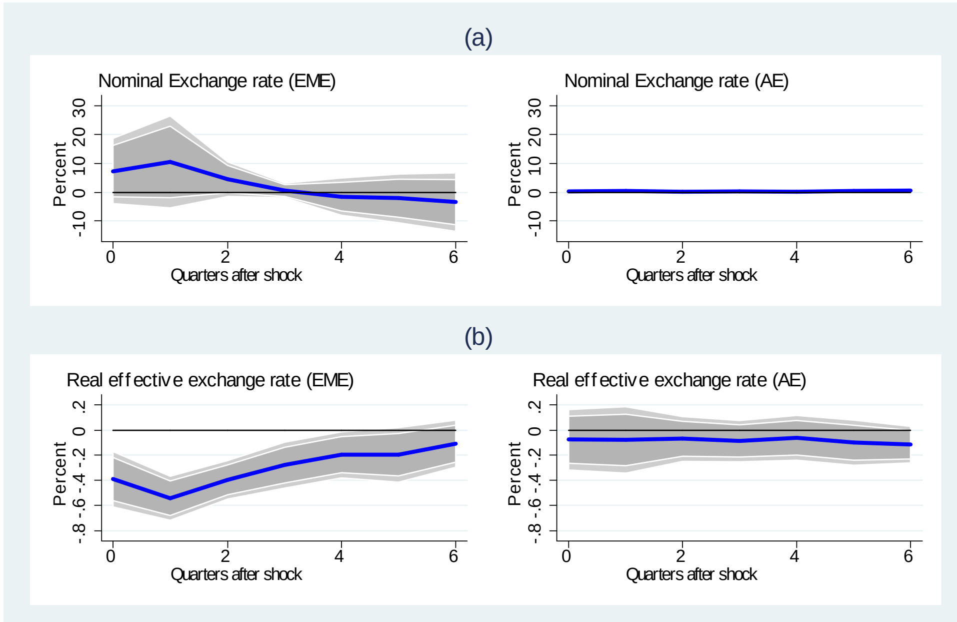

Figure 4-4: Local projection responses for (a) Nominal exchange rate; (b) Real effective exchange rate with VXO impulse

Variable	Standard deviation×100								
	TR-CPI-ER : $\phi_X =$			TR-PPI-ER : $\phi_X =$			ERR : $\phi_\pi^e =$		
	0.05	0.2	0.5	0.05	0.2	0.5	0.16	0.3	0.8
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Consumption	2.484	2.484	2.484	2.483	2.483	2.483	2.476	2.472	2.465
Output	2.473	2.412	2.344	2.446	2.394	2.334	1.602	1.261	0.661
Net exports	1.450	1.450	1.450	1.451	1.451	1.451	1.455	1.458	1.465
Inflation (PPI)	2.940	2.662	2.394	2.914	2.659	2.403	1.673	1.489	1.081
Inflation (CPI)	2.923	2.660	2.406	2.943	2.696	2.446	1.695	1.510	1.089
Nominal ER	1.478	1.116	0.749	1.449	1.124	0.784	0.246	0.430	0.857
REER	0.561	0.552	0.533	0.511	0.542	0.526	0.507	0.282	0.182
Interest rates	3.584	3.385	3.202	3.614	3.425	3.243	2.645	2.476	2.095

Table 4.3: Comparing second empirical moments for varying parameters in monetary policy rules

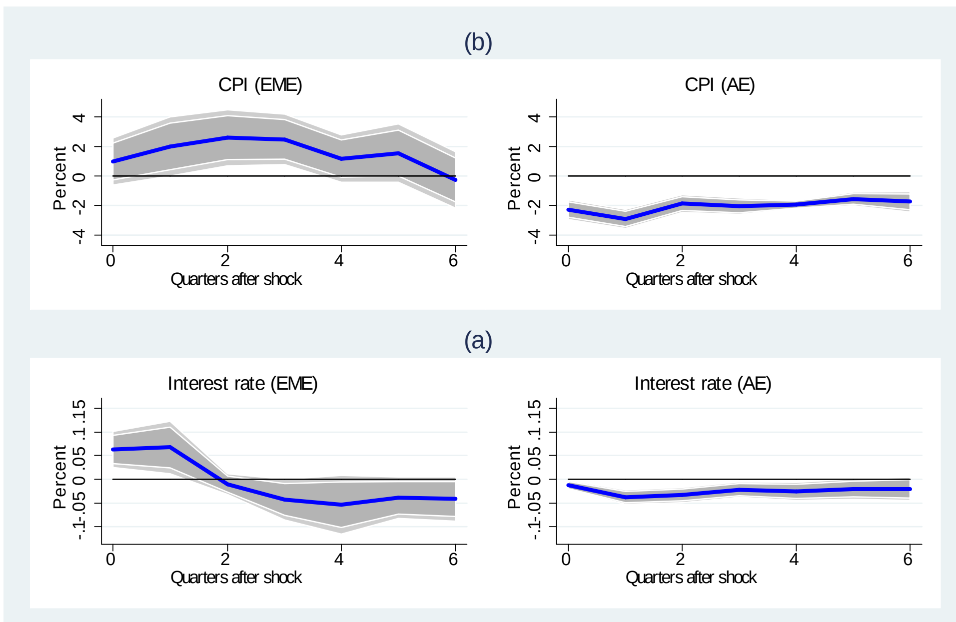

Figure 4-5: Local projection responses for (a) Consumer price index; (b) Nominal interest rates with VXO impulse

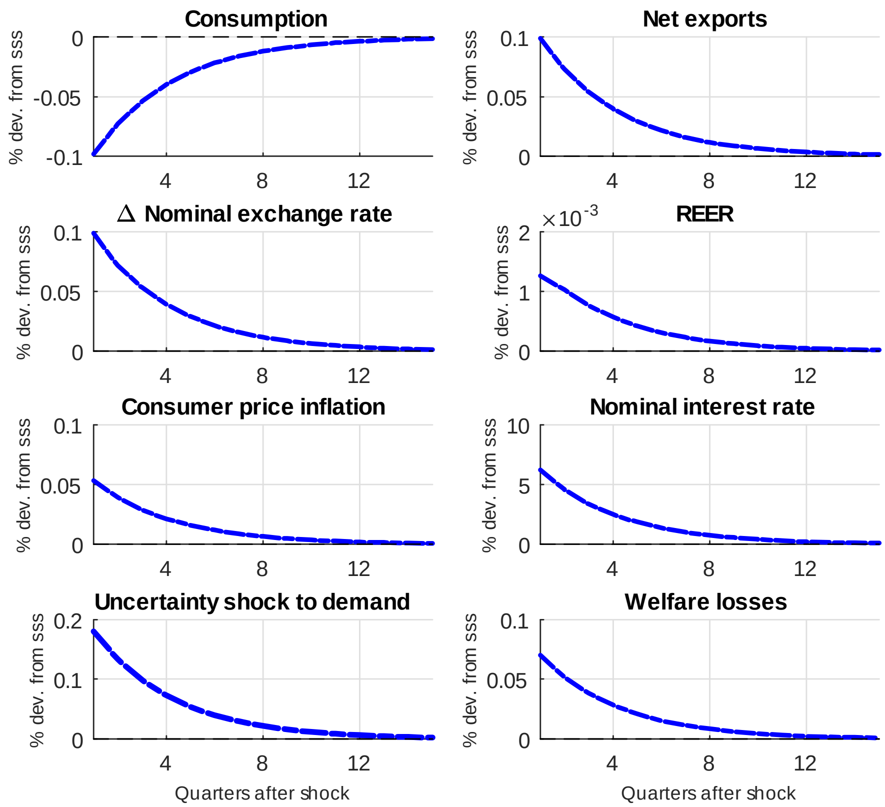

Figure 4-6: IRFs for a SOE to a one standard deviation shock to uncertainty in the foreign demand

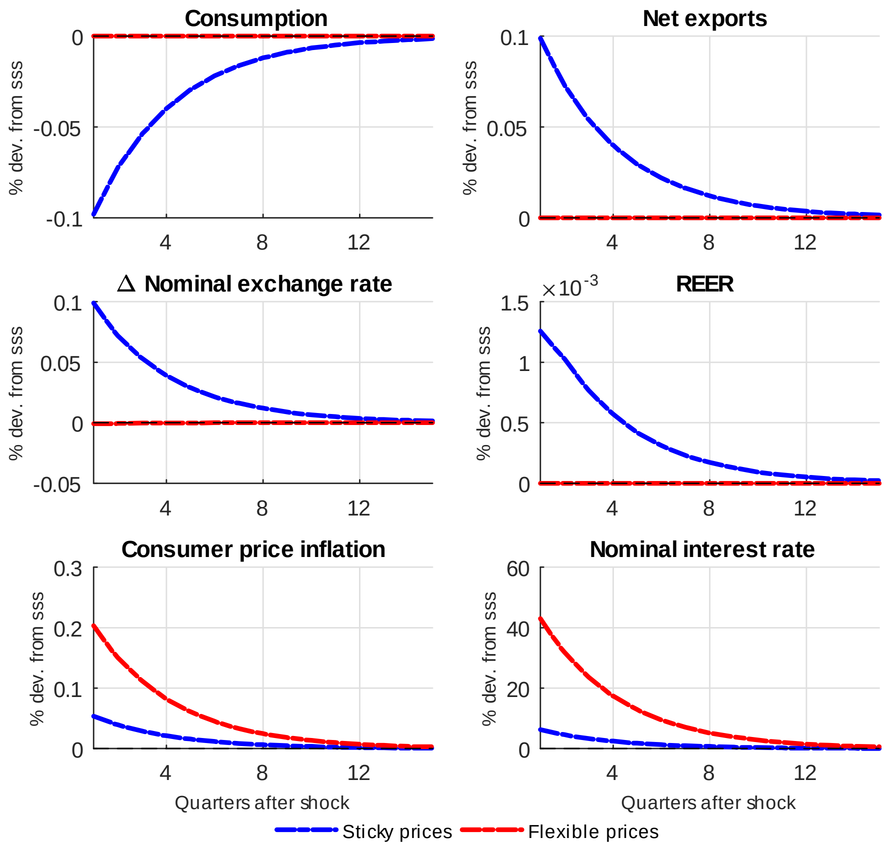

Figure 4-7: IRFs comparing the sticky price and flexible price allocation for a one standard deviation shock to uncertainty in foreign demand

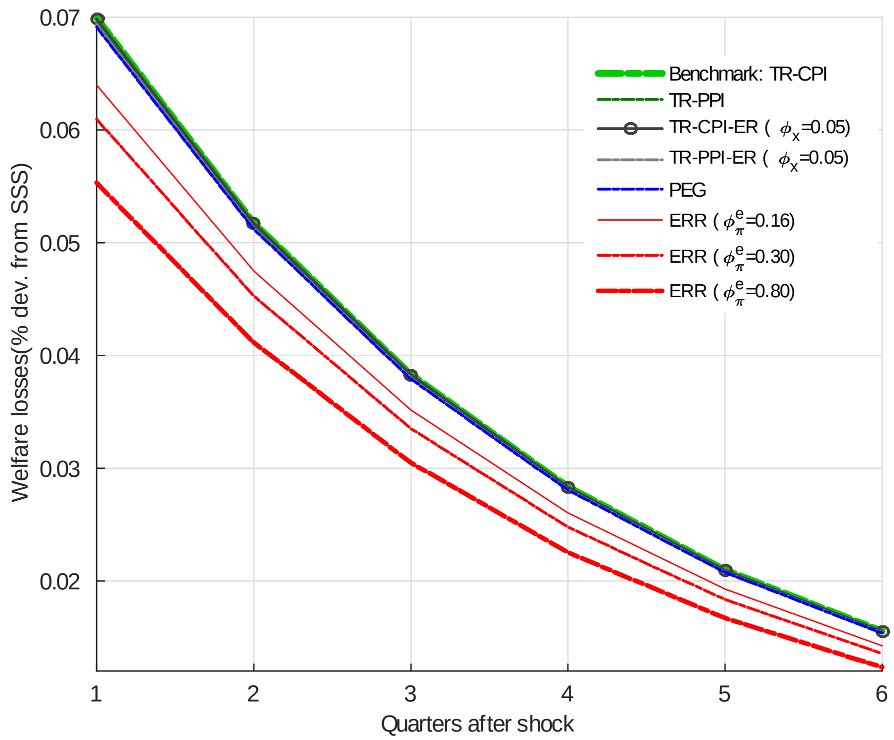

Figure 4-8: Welfare loss responses in a SOE under different monetary policy rules to one standard deviation shock to uncertainty in foreign demand

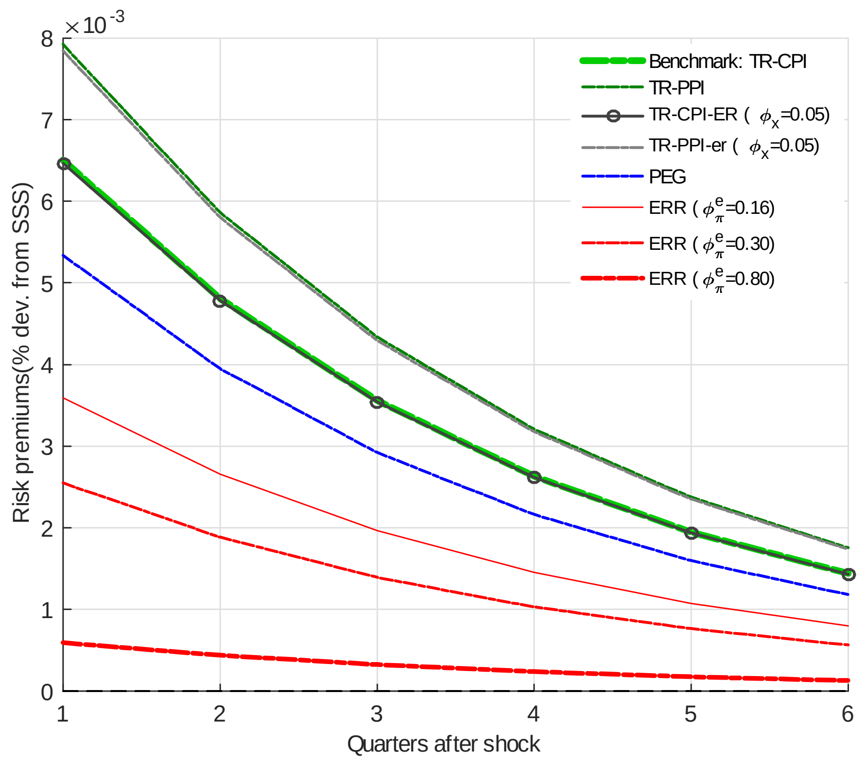

Figure 4-9: Risk premium responses in a SOE under different monetary policy rules to one standard deviation shock to uncertainty in foreign demand

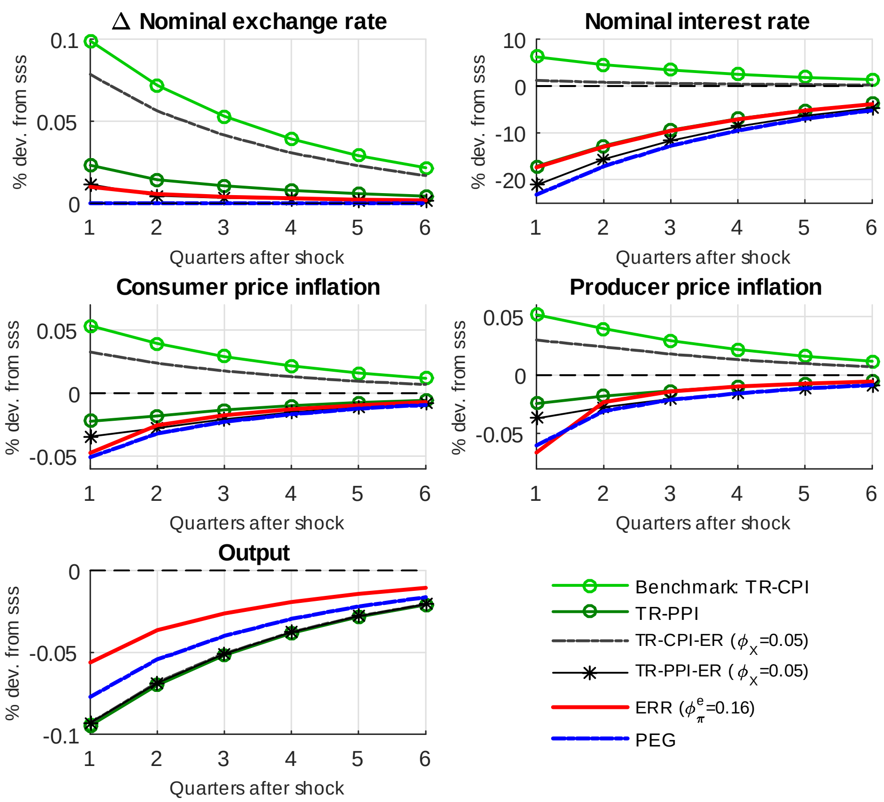

Figure 4-10: IRFs for a SOE under different monetary policy rules to a one standard deviation shock to uncertainty in foreign demand

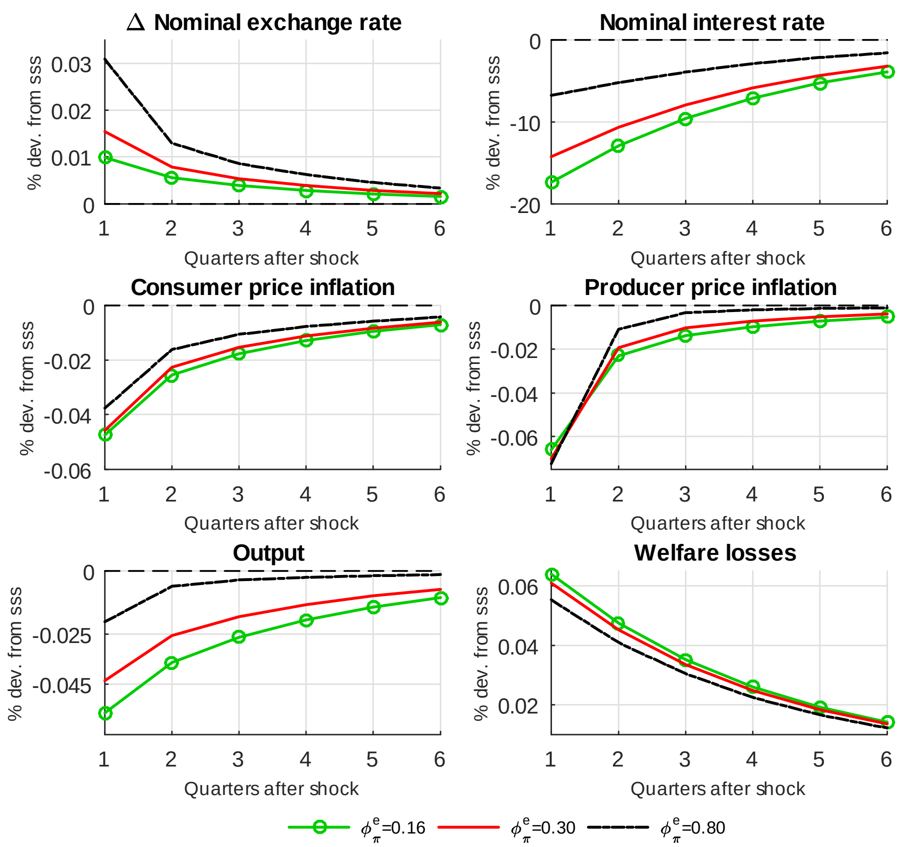

Figure 4-11: IRFs for a SOE under exchange rate rules with varying sensitivity to inflation (ϕ_π^e) for a one standard deviation shock to uncertainty in foreign demand

Appendix A

Technical Appendix: Chapter 2

A.1 Household optimization

- **Derivation of the demand function of each variety of good j: Equation** (2.11)

$$\max_{C_{s,t}(j)} \left[\int_0^1 C_{s,t}(j)^{\frac{\theta-1}{\theta}} \, dj \right]^{\frac{\theta}{\theta-1}} \text{ subject to}$$

$$\int_0^1 P_{s,t}(j) \, C_{s,t}(j) \, dj = Z_{s,t}$$

for a given level of expenditure level, $Z_{s,t}$. The above maximization problem can be written as the following Lagrangian,

$$\mathcal{L} = \left[\int_0^1 C_{s,t}(j)^{\frac{\theta-1}{\theta}} \, dj \right]^{\frac{\theta}{\theta-1}} - \lambda_t \left(\int_0^1 P_{s,t}(j) \, C_{s,t}(j) \, dj_1 - Z_{s,t} \right).$$

The first-order condition is given by,

$$C_{s,t}^{\frac{1}{\theta}} C_{s,t}(j)^{-\frac{1}{\theta}} = \lambda_t P_{s,t}(j)$$

for all $j \in [0,1]$. Using the above first order condition for any two varieties j_1, j_2 and eliminating λ_t we get,

$$C_{s,t}(j_1) = C_{s,t}(j_2)\left(\frac{P_{s,t}(j_1)}{P_{s,t}(j_2)}\right)^{-\theta}.$$

Now substituting $C_{s,t}(j_1)$ into $\int_0^1 P_{s,t}(j_1)\, C_{s,t}(j_1)\; dj_1 = Z_{s,t}$ and putting

$$\left[\int P_{s,t}(j_1)^{1-\theta}\; dj_1\right]^{\frac{1}{1-\theta}} = P_{s,t},$$

the aggregate price index of sector s, we get

$$C_{s,t}(j_2) = \left(\frac{P_{s,t}(j_2)}{P_{s,t}}\right)^{-\theta}\frac{Z_{s,t}}{P_{s,t}}$$

for all $j_2 \in [0,1]$. Also, substituting the term, $C_{s,t}(j_1)$, in the expression,

$$\left[\int_0^1 C_{s,t}(j_1)^{\frac{\theta-1}{\theta}}\; dj_1\right]^{\frac{\theta}{\theta-1}} = C_{s,t},$$

we get

$$\int_0^1 P_{s,t}(j_2)\, C_{s,t}(j_2)\, dj_2 = P_{s,t}C_{s,t} = Z_{s,t}.$$

Hence $C_{s,t}(j) = \left(\frac{P_{s,t}(j)}{P_{s,t}}\right)^{-\theta} C_{s,t}$ for all $j \in [0,1]$ where $s = OG,\, V,\, M$.

- **Derivation of the demand function for each sector's good: Equation** (2.7) **-** (2.10)

The optimization exercise is to,

$$\max_{\{C_{A,t},C_{M,t}\}} \frac{(C_{A,t})^{\delta}\,(C_{M,t})^{1-\delta}}{\delta^{\delta}(1-\delta)^{(1-\delta)}} \text{ subject to}$$

$$P_{A,t}C_{A,t} + P_{M,t}C_{M,t} = Z_t,$$

for a given level of expenditure level, Z_t. The above maximization problem can be written as the following Lagrangian,

$$\mathcal{L} = \frac{(C_{A,t})^{\delta}(C_{M,t})^{1-\delta}}{\delta^{\delta}(1-\delta)^{(1-\delta)}} - \lambda_t \left(P_{A,t}C_{A,t} + P_{M,t}C_{M,t} - Z_t\right).$$

The first order conditions with respect to $C_{A,t}$ and $C_{M,t}$ are given by,

$$\begin{aligned} \frac{\delta (C_{A,t})^{\delta-1}(C_{M,t})^{1-\delta}}{\delta^{\delta}(1-\delta)^{(1-\delta)}} &= \lambda_t P_{A,t} \\ \frac{(1-\delta)(C_{A,t})^{\delta}(C_{M,t})^{-\delta}}{\delta^{\delta}(1-\delta)^{(1-\delta)}} &= \lambda_t P_{M,t} \end{aligned}$$

respectively. Eliminating λ_t, we get,

$$C_{M,t} = \frac{(1-\delta)}{\delta} C_{A,t} \left(\frac{P_{M,t}}{P_{A,t}}\right)^{-1}.$$

Now substituting the term, $C_{M,t}$, into the expression, $\frac{(C_{A,t})^{\delta}(C_{M,t})^{1-\delta}}{\delta^{\delta}(1-\delta)^{(1-\delta)}}$, and setting $(P_{A,t})^{\delta}(P_{M,t})^{1-\delta} = P_t$, the aggregate price index of the economy, is

$$C_{A,t} = \delta \left(\frac{P_{A,t}}{P_t}\right)^{-1} C_t.$$

Put $C_{A,t} = \delta \left(\frac{P_{A,t}}{P_t}\right)^{-1} C_t$ in the term, $C_{M,t}$, which gives

$$C_{M,t} = (1-\delta)\left(\frac{P_{M,t}}{P_t}\right)^{-1} C_t.$$

The above two equations can be re-written as

$$\begin{aligned} P_{A,t}C_{A,t} &= \delta P_t C_t \\ P_{M,t}C_{M,t} &= (1-\delta) P_t C_t \end{aligned}$$

Adding the above two equations we get $P_{A,t}C_{A,t} + P_{M,t}C_{M,t} = P_tC_t$. Hence $Z_t = P_tC_t$. Similarly, maximizing $\frac{(C_{OG,t})^{(1-\mu)}(C_{V,t})^{\mu}}{\mu^{\mu}(1-\mu)^{(1-\mu)}}$ subject to the constraint $P_{OG,t}C_{OG,t} + P_{V,t}C_{V,t} = Z_{A,t}$ we get equations (2.9) and (2.10).

- **Derivation of the Euler equation and labor supply equation** (2.13) **and** (2.14)

$$\max_{C_t,N_t,B_{t+1}} E_0 \sum_{t=0}^{\infty} \left[\frac{(\Gamma_t C_t)^{1-\sigma}}{1-\sigma} - \frac{(N_t)^{1+\psi}}{1+\psi} \right]$$

subject to

$$\int_0^1 P_{OG,t}(j)\, C_{OG,t}(j)\ dj + \int_0^1 P_{V,t}(j)\, C_{V,t}(j)\ dj + \int_0^1 P_{M,t}(j)\, C_{M,t}(j)\ dj + E_t\{Q_{t+1}B_{t+1}\}$$

$$= B_t + W_tN_t + T_t + Div_t.$$

The Lagrangian for the above problem can be written as:

$$\mathcal{L} = E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \left[\frac{(\Gamma_t C_t)^{1-\sigma}}{1-\sigma} - \frac{(N_t)^{1+\psi}}{1+\psi} \right] - \lambda_t \left[P_tC_t + E_t\{Q_{t+1}B_{t+1}\} - B_t - W_tN_t - T_t - Div_t \right] \right\}$$

The first order conditions for C_t, N_t and B_{t+1} are given by:

$$\begin{aligned}
\frac{\partial \mathcal{L}}{\partial C_t} &= (\Gamma_t)^{1-\sigma}(C_t)^{-\sigma} - \lambda_t P_t = 0 \\
\frac{\partial \mathcal{L}}{\partial N_t} &= -(N_t)^{\psi} + \lambda_t W_t = 0 \\
\frac{\partial \mathcal{L}}{\partial B_{t+1}} &= -\beta^t \lambda_t E_t\{Q_{t,t+1}\} + \beta^{t+1} E_t\{\lambda_{t+1}\} = 0,
\end{aligned}$$

respectively. Using the first two conditions we get the labor supply equation (2.14), and using the first and the last condition we get the Euler equation (2.13). In the Euler equation, $R_t = \frac{1}{E_t\{Q_{t,t+1}\}}$.

A.2 Firm optimization

- **Derivation of the price setting equation: The grain sector equation** (2.27)

  The optimization problem is given by,

$$\max_{P_{OG,t}(j)} \{P_{OG,t}(j)[Y_{OG,t}(j)+Y_{PG,t}] - MC_{G,t}[Y_{OG,t}(j)+Y_{PG,t}]\}$$

  subject to the demand constraint

$$Y_{OG,t}(j) = \left(\frac{P_{OG,t}(j)}{P_{OG,t}}\right)^{-\theta} Y_{OG,t}.$$

  The first order condition is given by:

$$Y_{OG,t}(j) + Y_{PG,t} + P_{OG,t}(j)\frac{\partial Y_{OG,t}(j)}{\partial P_{OG,t}(j)} - MC_{G,t}\frac{\partial Y_{OG,t}(j)}{\partial P_{OG,t}(j)} = 0.$$

$$\text{Now } \frac{\partial Y_{OG,t}(j)}{\partial P_{OG,t}(j)} = -\theta\left(\frac{P_{OG,t}(j)}{P_{OG,t}}\right)^{-\theta}\frac{1}{P_{OG,t}(j)}Y_{OG,t} = -\theta\frac{Y_{OG,t}(j)}{P_{OG,t}(j)}$$

  Simplifying we get,

$$Y_{OG,t}(j) + Y_{PG,t} - \theta Y_{OG,t}(j) + \theta MC_{G,t}\frac{Y_{OG,t}(j)}{P_{OG,t}(j)} = 0,$$

$$P_{OG,t}(j)\left((1-\theta)Y_{OG,t}(j) + Y_{PG,t}\right) = -\theta MC_{G,t}Y_{OG,t}(j),$$

$$P_{OG,t}(j) = \frac{\theta MC_{G,t}}{\theta - 1 - \frac{Y_{PG,t}}{Y_{OG,t}(j)}}.$$

  Similarly one can solve for the price setting equation in the vegetable sector as given in equation (2.28).

- **Derivation of the price setting equation: manufacturing sector equations**

(2.29) **and** (2.36)

The optimization problem is given by,

$$\max_{P^*_{M,t}(j)} E_t \sum_{k=0}^{\infty} \alpha_M^k Q_{t,t+k}[P^*_{M,t}(j)\, Y_{M,t+k}(j) - MC_{M,t+k} Y_{M,t+k}(j)]$$

subject to the demand constraint

$$Y_{M,t+k}(j) = \left(\frac{P^*_{M,t}(j)}{P_{M,t+k}}\right)^{-\theta} Y_{M,t+k}.$$

The first order condition is given by:

$$E_t \sum_{k=0}^{\infty} \alpha_M^k Q_{t,t+k} \left[Y_{M,t+k}(j) + P^*_{M,t}(j) \frac{\partial Y_{M,t+k}(j)}{\partial P^*_{M,t}(j)} - MC_{M,t+k} \frac{\partial Y_{M,t+k}(j)}{\partial P^*_{M,t}(j)}\right] = 0$$

$$\begin{aligned} \text{Now } \frac{\partial Y_{M,t+k}(j)}{\partial P^*_{M,t}(j)} &= -\theta \left(\frac{P^*_{M,t}(j)}{P_{M,t+k}}\right)^{-\theta} \frac{1}{P^*_{M,t}(j)} Y_{M,t+k} \\ &= -\theta \frac{Y_{M,t+k}(j)}{P^*_{M,t}(j)}. \end{aligned}$$

Simplifying we get,

$$E_t \sum_{k=0}^{\infty} \alpha_M^k Q_{t,t+k} \left[Y_{M,t+k}(j) - \theta Y_{M,t+k}(j) + \theta MC_{M,t+k} \frac{Y_{M,t+k}(j)}{P^*_{M,t}(j)}\right] = 0,$$

$$P^*_{M,t}(j)\, E_t \sum_{k=0}^{\infty} \alpha_M^k Q_{t,t+k} (1-\theta)\, Y_{M,t+k}(j) = -E_t \sum_{k=0}^{\infty} (\beta \alpha_M)^t\, \theta MC_{M,t+k} Y_{M,t+k}(j),$$

$$P^*_{M,t}(j) = \frac{\theta}{\theta - 1} \frac{E_t \sum_{k=0}^{\infty} \alpha_M^k Q_{t,t+k} Y_{M,t+k}(j) MC_{M,t+k}}{E_t \sum_{k=0}^{\infty} \alpha_M^k Q_{t,t+k} Y_{M,t+k}(j)}.$$

We know that

$$P_{M,t} \equiv \left(\int_0^1 P_{M,t}(j)^{1-\theta} dj\right)^{\frac{1}{1-\theta}},$$

is the aggregate price index of this sector. Since demand for each variety of goods in this sector is symmetric and all firms revise their prices with a common maximization problem we can drop the $'j'$ so that $P^{*}_{M,t}(j) = P_{M,t}$ for all j. For all the firms who do not get to choose their prices $P_{M,t}(j) = P_{M,t-1}(j)$. Hence, the aggregate price index can be written as

$$P^{1-\theta}_{M,t} = \int_0^1 P_{M,t}(j)^{1-\theta} dj = (1-\alpha_M)(P^{*}_{M,t})^{1-\theta} + \alpha_M \int_0^1 P_{M,t-1}(j)^{1-\theta} dj.$$

Note that the expression, $\alpha_M \int_0^1 P_{M,t-1}(j)^{1-\theta} dj$, is simply a subset of the prices in $t-1$, with each price appearing in the period t distribution of unchanged prices with the same relative frequency as in the period $t-1$ price distribution (Ch-3, Woodford, 2003). Therefore,

$$P_{M,t} = \left[(1-\alpha_M)(P^{*}_{M,t})^{1-\theta} + \alpha_M (P_{M,t-1})^{1-\theta}\right]^{\frac{1}{(1-\theta)}}.$$

- **Market Clearing: Derivation for equation** (2.35).

  Equation (2.34) can be re-written as,

$$\begin{aligned} Y_t &= C_t + \frac{P_{OG,t}}{P_t} Y_{PG,t} \\ &= C_t + \frac{P_{OG,t}}{P_{A,t}} \frac{P_{A,t}}{P_t} Y_{PG,t} \\ &= C_t + \frac{P_{OG,t}}{(P_{OG,t})^{1-\mu}(P_{V,t})^{\mu}} \frac{P_{A,t}}{(P_{A,t})^{\delta}(P_{M,t})^{1-\delta}} Y_{PG,t} \\ &= C_t + (T_{OGV,t})^{\mu}(T_{AM,t})^{(1-\delta)} Y_{PG,t}. \end{aligned}$$

A.3 Steady state

- **Derivation of steady states: Section 2.3.2**

  Using the fact that $Q_{t,t+k} = \beta^k \left(\frac{\Gamma_{t+1}}{\Gamma_t}\right)^{1-\sigma} \left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} \left(\frac{P_t}{P_{t+1}}\right)$, in the steady state

$Q_{t,t+k} = \beta^k$. Thus equations (2.29) and (2.31) in the steady state can be written as,

$$\begin{aligned} P_M^* &= \frac{\theta}{\theta-1} \frac{E_t \sum_{t=0}^{\infty} (\beta\alpha_M)^t Y_M MC_M}{E_t \sum_{t=0}^{\infty} (\beta\alpha_M)^t Y_M}, \\ &= \frac{\theta}{\theta-1} MC_M, \end{aligned}$$

and

$$(P_M)^{1-\theta} = \alpha_M (P_M)^{1-\theta} + (1-\alpha_M)(P_M^*)^{1-\theta} \text{ respectively.}$$

The above equation implies,

$$\begin{aligned} P_M^* &= P_M \\ &= \frac{\theta}{\theta-1} MC_M. \end{aligned}$$

Similarly considering the price setting equation in the grain sector,

$$P_{OG} = \frac{\theta(1-c_p)}{(\theta-1)(1-c_p)-c_p} MC_G, \text{ where } c_p = \frac{Y_{PG}}{Y_G},$$

and in the vegetable sector,

$$P_V = \frac{\theta}{\theta-1} MC_V.$$

The aggregate price index at the steady state is:

$$P = (P_{OG})^{(1-\mu)\delta} (P_V)^{\mu\delta} (P_M)^{1-\delta}.$$

Using equation (2.22), $MC_s = W$ for $s = G, V, M$, as $A_s = 1$. Substituting these values in the above aggregate price index we get,

$$
\begin{aligned}
P &= \left(\frac{(\theta-1)(1-c_p)}{(\theta-1)(1-c_p)-c_p}\right)^{(1-\mu)\delta} \frac{\theta}{\theta-1}W. \\
P &= \gamma^{-(1-\mu)\delta}\frac{\theta}{\theta-1}W \quad \text{where } \gamma = \frac{(\theta-1)(1-c_p)-c_p}{(\theta-1)(1-c_p)}.
\end{aligned}
$$

Since, $P_M = P_V = \frac{\theta}{\theta-1}W$ and $P_{OG} = \frac{\theta(1-c_p)}{(\theta-1)(1-c_p)-c_p}W$,

$$
\begin{aligned}
\frac{P_V}{P} &= \frac{P_M}{P} = \gamma^{(1-\mu)\delta} \text{ and} \\
\frac{P_{OG}}{P} &= \gamma^{(1-\mu)\delta-1}.
\end{aligned}
$$

Now from the demand functions,

$$
\begin{aligned}
\frac{C_{OG}}{C} &= \frac{(1-\mu)\delta P}{P_{OG}} \\
&= (1-\mu)\delta\gamma^{-\delta(1-\mu)+1}
\end{aligned}
$$

$$
\begin{aligned}
\frac{C_V}{C} &= \frac{\mu\delta P}{P_V} \\
&= \mu\delta\gamma^{-\delta(1-\mu)}, \text{ and,} \\
\frac{C_M}{C} &= \frac{(1-\delta)P}{P_M} \\
&= (1-\delta)\,\gamma^{-\delta(1-\mu)}.
\end{aligned}
$$

We can re-write the steady state labor supply equation (2.36) in the steady state as,

$$
\begin{aligned}
N &= N_{OG} + N_{PG} + N_V + N_M \\
&= \frac{Y_{OG}}{A_G} + \frac{Y_{PG}}{A_G} + \frac{Y_V}{A_V} + \frac{Y_M}{A_M} \\
&= C_{OG} + C_V + C_M + Y_{PG} \text{ (Goods Market Equilibrium).}
\end{aligned}
$$

Using the above values from the steady state consumption demands,

$$N = \gamma^{-\delta(1-\mu)} \left[1 + (\gamma - 1)(1 - \mu)\delta\right] C + Y_{PG}$$

A.4 Log linearized model

- **Derivation of the log-linearized model: Equations** (2.39), (2.40), (2.41a), (2.36), (2.47) **and** (2.51) **in section 3.3**

Equation (2.39): Using a first order Taylor approximation in equation (2.13) yields,

$$E_t \left\{ \begin{array}{c} \beta R + \beta R \left(\frac{R_{t+1}-R}{R}\right) + (1-\sigma)\beta R \left(\frac{\Gamma_{t+1}-\Gamma}{\Gamma}\right) \\ -(1-\sigma)\beta R \left(\frac{\Gamma_t-\Gamma}{\Gamma}\right) - \sigma\beta R \left(\frac{C_{t+1}-C}{C}\right) + \sigma\beta R \left(\frac{C_t-C}{C}\right) \\ +\beta R \left(\frac{C_t-C}{C}\right) + \beta R \left(\frac{P_t-P}{P}\right) - \beta R \left(\frac{P_{t+1}-P}{P}\right) \end{array} \right\} \approx 1.$$

Now for variable X_t , $\frac{X_t-X}{X} \approx \ln(X_t) - \ln(X) \approx \widehat{X}_t$. Using the steady state value of Euler Equation, $\beta R = 1$, we get

$$E_t \left\{ \widehat{R}_t + (1-\sigma)\widehat{\Gamma}_{t+1} - (1-\sigma)\widehat{\Gamma}_t - \sigma \widehat{C}_{t+1} + \sigma \widehat{C}_t + \widehat{P}_t - \widehat{P}_{t+1} \right\} \approx 0.$$

Re-arranging terms and using $\widehat{P}_{t+1} - \widehat{P}_t = \pi_{t+1}$, we get

$$\widehat{C}_t = E_t\{\widehat{C}_{t+1}\} - \frac{1}{\sigma}[(\widehat{R}_t - E_t\{\pi_{t+1}\}) + (1-\sigma)E_t\{\Delta\widehat{\Gamma}_{t+1}\}].$$

Equation (2.40): Using a first order Taylor approximation in equation (2.14) , we have

$$\frac{N^{\psi}}{\Gamma^{1-\sigma}C^{-\sigma}}+\psi\frac{N^{\psi}}{\Gamma^{1-\sigma}C^{-\sigma}}\left(\frac{N_{t+1}-N}{N}\right)-(1-\sigma)\frac{N^{\psi}}{\Gamma^{1-\sigma}C^{-\sigma}}\left(\frac{\Gamma_t-\Gamma}{\Gamma}\right)+$$

$$\sigma\frac{N^{\psi}}{\Gamma^{1-\sigma}C^{-\sigma}}\left(\frac{C_t-C}{C}\right)\approx\frac{W}{P}+\frac{W}{P}\left(\frac{W_t-W}{W}\right)-\frac{W}{P}\left(\frac{P_t-P}{P}\right).$$

This implies that,

$$\widehat{W}_t-\widehat{P}_t=\psi\widehat{N}_t+\sigma\widehat{C}_t-(1-\sigma)\widehat{\Gamma}_t$$

Equation $(2.41a)$: Using a first order Taylor approximation of equation $(2.23a)$, we get

$$mc_G+mc_G\left(\frac{mc_{G,t}-mc_G}{mc_G}\right)\approx\frac{1}{A_G}\frac{W}{P}\left(T_{AM}\right)^{-(1-\delta)}\left(T_{OGV}\right)^{-\mu}$$

$$-\frac{1}{A_G}\frac{W}{P}\left(T_{AM}\right)^{-(1-\delta)}\left(T_{OGV}\right)^{-\mu}\left[\left(\frac{A_{G,t}-A_G}{A_G}\right)+\left(\frac{W_t-W}{W}\right)-\left(\frac{P_t-P}{P}\right)\right.$$

$$\left.-(1-\delta)\left(\frac{T_{AM,t}-T_{AM}}{T_{AM}}\right)-\mu\left(\frac{T_{OG,V,t}-T_{OG,V}}{T_{OG,V}}\right)\right]$$

Simplifying the above expression using the steady state expression, $mc_G=\frac{1}{A_G}\frac{W}{P}\left(T_{AM}\right)^{-(1-\delta)}\left(T_{OGV}\right)^{-\mu}$, we get

$$\widehat{mc}_{G,t}=\widehat{W}_t-\widehat{P}_t-\widehat{A}_{G,t}-(1-\delta)\widehat{T}_{AM,t}-\mu\widehat{T}_{OGV,t}.$$

We can derive $(2.41b)$ and $(2.41c)$ in a similar way.

The log-linearized sectoral employment equations can be obtained by taking a first order Taylor approximation of equation (2.26) and noting that

$$N_{G,t} = \frac{1}{A_{G,t}} \left\{ Y_{PG,t} \; + \; Y_{OG,t} Z_{OG,t} \right\},$$

where a first order approximation to the dispersion term, $\widehat{Z}_{s,t} \approx 0$. (For details see Gali (2008), Ch-3)

Note that:

$$\begin{aligned}
\frac{P_t}{P_{A,t}} &= \frac{(P_{A,t})^{\delta} (P_{M,t})^{1-\delta}}{P_{A,t}} = \left(\frac{P_{A,t}}{P_{M,t}} \right)^{-(1-\delta)} = (T_{AM,t})^{-(1-\delta)} \\
\frac{P_t}{P_{M,t}} &= \frac{(P_{A,t})^{\delta} (P_{M,t})^{1-\delta}}{P_{M,t}} = \left(\frac{P_{A,t}}{P_{M,t}} \right)^{\delta} = (T_{AM,t})^{\delta} \\
\frac{P_{A,t}}{P_{OG,t}} &= \frac{(P_{OG,t})^{1-\mu} (P_{V,t})^{\mu}}{P_{OG,t}} = \left(\frac{P_{OG,t}}{P_{V,t}} \right)^{-\mu} = (T_{OGV,t})^{-\mu} \\
\frac{P_{A,t}}{P_{V,t}} &= \frac{(P_{OG,t})^{1-\mu} (P_{V,t})^{\mu}}{P_{V,t}} = \left(\frac{P_{OG,t}}{P_{V,t}} \right)^{1-\mu} = (T_{OGV,t})^{1-\mu}.
\end{aligned}$$

We use the above four equations to re-write the demand functions $C_{OG,t}$, $C_{M,t}$, $C_{V,t}$ in terms of C_t and the terms of trade terms $(T_{AM,t}$ & $T_{OGV,t})$. Using the goods market equilibrium and the demand functions it is easy to derive equations $(2.43a)$–$(2.43c)$ using a first order Taylor's approximation. Log linearization of the aggregate goods market clearing equation (2.35), gives us,

$$\begin{aligned}
Y + Y \frac{(Y_t - Y)}{Y} \approx\; & C + (T_{OGV})^{\mu} (T_{AM})^{1-\delta} Y_{PG} + \frac{(C_t - C)}{C} C \\
& + \mu (T_{OGV})^{\mu-1} (T_{AM})^{1-\delta} Y_{PG} \frac{(T_{OGV,t} - T_{OGV})}{T_{OGV}} T_{OGV} \\
& + (1-\delta) (T_{OGV})^{\mu} (T_{AM})^{-\delta} Y_{PG} \frac{(T_{AM,t} - T_{AM})}{T_{AM}} T_{AM} \\
& + (T_{OGV})^{\mu} (T_{AM})^{1-\delta} \frac{(Y_{PG,t} - Y_{PG})}{Y_{PG}} Y_{PG}
\end{aligned}$$

$$\widehat{Y}_t = \frac{C}{Y} \widehat{C}_t + \frac{(T_{OGV})^{\mu} (T_{AM})^{1-\delta} Y_{PG}}{Y} \left[\mu \widehat{T}_{OGV,t} + (1-\delta) \widehat{T}_{AM,t} + \widehat{Y}_{PG,t} \right]$$

Note

$$\frac{(T_{OGV})^{\mu}\,(T_{AM})^{1-\delta}\,Y_{PG}}{Y} = \frac{\gamma^{-\mu}\gamma^{-(1-\mu)(1-\delta)}}{Y}Y_{PG} = \gamma^{[\delta(1-\mu)-1]}c_p s_g = \lambda_c$$

and

$$\frac{C}{Y} = 1 - \lambda_c.$$

Therefore,

$$\widehat{Y}_t = (1-\lambda_c)\widehat{C}_t + \lambda_c\left[\mu\widehat{T}_{OGV,t} + (1-\delta)\,\widehat{T}_{AM,t} + \widehat{Y}_{PG,t}\right].$$

Equation (2.36) can be written as,

$$N_t = N_{OG,t} + N_{PG,t} + N_{V,t} + N_{M,t},$$

$$N_t = \frac{Y_{OG,t}}{A_G} + \frac{Y_{PG,t}}{A_G} + \frac{Y_{V,t}}{A_{V,t}} + \frac{Y_{M,t}Z_{M,t}}{A_{M,t}}.$$

Log linearizing Equation (2.36), we get

$$\begin{aligned} N + N\left(\frac{N_t - N}{N}\right) &\approx \frac{Y_{OG}}{A_G} + \frac{Y_{PG}}{A_G} + \frac{Y_V}{A_V} + \frac{Y_M}{A_M} + \frac{Y_{OG}}{A_{G,t}}\left[\left(\frac{Y_{OG,t} - Y_{OG}}{Y_{OG}}\right) - \left(\frac{A_{G,t} - A_G}{A_G}\right)\right] \\ &+\frac{Y_{PG}}{A_{G,t}}\left[\left(\frac{Y_{PG,t} - Y_{PG}}{Y_{PG}}\right) - \left(\frac{A_{G,t} - A_G}{A_G}\right)\right] \\ &+\frac{Y_V}{A_V}\left[\left(\frac{Y_{V,t} - Y_V}{Y_V}\right) - \left(\frac{A_{V,t} - A_V}{A_V}\right)\right] \\ &+\frac{Y_M Z_M}{A_{M,t}}\left[\left(\frac{Y_{M,t} - Y_M}{Y_M}\right) + \left(\frac{Z_{M,t} - Z_M}{Z_M}\right) - \left(\frac{A_{M,t} - A_M}{A_M}\right)\right]. \end{aligned}$$

Using $Z_M = 1$ and $\widehat{Z}_{M,t} \approx 0$ (as shown in Gali (2008)), we get

$$\begin{aligned} N\widehat{N}_t &= Y_{OG}\left(\widehat{Y}_{OG,t} - \widehat{A}_{G,t}\right) + Y_{PG}\left(\widehat{Y}_{PG,t} - \widehat{A}_{G,t}\right) + Y_V\left(\widehat{Y}_{V,t} - \widehat{A}_{V,t}\right) + Y_M\left(\widehat{Y}_{M,t} - \widehat{A}_{M,t}\right) \\ N\widehat{N}_t &= C_{OG}\left(\widehat{C}_{OG,t} - \widehat{A}_{G,t}\right) + Y_{PG}\left(\widehat{Y}_{PG,t} - \widehat{A}_{G,t}\right) + C_V\left(\widehat{C}_{V,t} - \widehat{A}_{V,t}\right) + C_M\left(\widehat{C}_{M,t} - \widehat{A}_{M,t}\right). \end{aligned}$$

Using steady state equations (2.37a) – (2.37b) in Section 2.3.2, we get

$$N\widehat{N}_t = \gamma^{-\delta(1-\mu)}C\left[(1-\mu)(\gamma-1)\delta\left(\widehat{C}_{OG,t} - \widehat{A}_{G,t}\right) + \mu\delta\left(\widehat{C}_{V,t} - \widehat{A}_{V,t}\right) + \right.$$
$$\left.(1-\delta)\left(\widehat{C}_{M,t} - \widehat{A}_{M,t}\right)\right] + Y_{PG}\left(\widehat{Y}_{PG,t} - \widehat{A}_{G,t}\right)$$
$$N\widehat{N}_t = \gamma^{-\delta(1-\mu)}\left[\widehat{C}_t - \widehat{A}_t + (1-\mu)(\gamma-1)\delta\left(\widehat{Y}_{OG,t} - \widehat{A}_{G,t}\right)\right]C + Y_{PG}\left(\widehat{Y}_{PG,t} - \widehat{A}_{G,t}\right)$$
$$\text{where } \widehat{C}_t = (1-\mu)\delta\widehat{C}_{OG,t} + \mu\delta\widehat{C}_{V,t} + (1-\delta)\widehat{C}_{M,t}$$
$$\widehat{A}_t = (1-\mu)\delta\widehat{A}_{G,t} + \mu\delta\widehat{A}_{V,t} + (1-\delta)\widehat{A}_{M,t}.$$

Using equation (2.38) ,

$$\widehat{N}_t = \frac{\gamma^{-\delta(1-\mu)}\left[\widehat{C}_t - \widehat{A}_t + (1-\mu)(\gamma-1)\delta\left(\widehat{Y}_{OG,t} - \widehat{A}_{G,t}\right)\right]C + Y_{PG}\left(\widehat{Y}_{PG,t} - \widehat{A}_{G,t}\right)}{\gamma^{-\delta(1-\mu)}\left[1 + (1-\mu)(\gamma-1)\delta\right]C + Y_{PG}}.$$

Using (2.35) at the steady state, $Y = C + \frac{P_{OG}}{P}Y_{PG}$,

$$\begin{aligned} \frac{Y_{PG}}{C} &= \frac{Y_{PG}}{Y - \gamma^{[\delta(1-\mu)-1]}Y_{PG}} = \frac{\frac{Y_{PG}}{Y_G}}{\frac{Y - \gamma^{[\delta(1-\mu)-1]}Y_{PG}}{Y_G}} \\ &= \frac{c_p s_g}{1 - \gamma^{[\delta(1-\mu)-1]}c_p s_g} \text{where } s_g = \frac{Y_G}{Y}, c_p = \frac{Y_{PG}}{Y_G}. \end{aligned}$$

$$\begin{aligned} \widehat{N}_t &= \frac{\left(1 - \gamma^{[\delta(1-\mu)-1]}c_p s_g\right)\gamma^{-\delta(1-\mu)}\left[\widehat{C}_t - \widehat{A}_t + (1-\mu)(\gamma-1)\delta\left(\widehat{Y}_{OG,t} - \widehat{A}_{G,t}\right)\right]}{\gamma^{-\delta(1-\mu)}\left[1 + (1-\mu)\delta\gamma\right]\left(1 - \gamma^{[\delta(1-\mu)-1]}c_p s_g\right) + c_p s_g} \\ &\quad + \frac{c_p s_g\left(\widehat{Y}_{PG,t} - \widehat{A}_{G,t}\right)}{\gamma^{-\delta(1-\mu)}\left[1 + (1-\mu)\delta\gamma\right]\left(1 - \gamma^{[\delta(1-\mu)-1]}c_p s_g\right) + c_p s_g}. \end{aligned}$$

$$\widehat{N}_t = \Theta_1 \left[\widehat{C}_t - \widehat{A}_t + (1-\mu)(\gamma-1)\delta \left(\widehat{Y}_{OG,t} - \widehat{A}_{G,t} \right) \right] + \Theta_2 \left(\widehat{Y}_{PG,t} - \widehat{A}_{G,t} \right),$$

$$\text{where } \Theta_1 = \frac{\left(1-\gamma^{[\delta(1-\mu)-1]} c_p s_g\right) \gamma^{-\delta(1-\mu)}}{\gamma^{-\delta(1-\mu)} \left[1+(1-\mu)(\gamma-1)\delta\right] (1-\gamma^{[\delta(1-\mu)-1]} c_p s_g) + c_p s_g}$$

$$\Theta_2 = \frac{c_p s_g}{\gamma^{-\delta(1-\mu)} \left[1+(1-\mu)(\gamma-1)\delta\right] (1-\gamma^{[\delta(1-\mu)-1]} c_p s_g) + c_p s_g}.$$

Equation (2.47) is the New-Keynesian Phillips Curve for the manufacturing sector derived by log-linearizing (2.29) and (2.31) (for details see Gali (2008) Ch-3)).

Equation (2.51) : Log-linearizing real marginal cost, $mc_{G,t}$, as in (2.27) , and using a first order Taylor approximation we get

$$mc_{G,t} = \frac{\theta-1}{\theta} - \frac{Y_{PG,t}}{\theta Y_{OG,t}}$$

$$mc_G + mc_G \left(\frac{mc_{G,t} - mc_G}{mc_G} \right) \approx \frac{\theta-1}{\theta} - \frac{Y_{PG}}{\theta Y_{OG}} + \frac{Y_{PG}}{\theta Y_{OG}} \left(\frac{Y_{OG,t} - Y_{OG}}{Y_{OG}} \right) - \frac{Y_{PG}}{\theta Y_{OG}} \left(\frac{Y_{PG,t} - Y_{PG}}{Y_{PG}} \right)$$

$$mc_G \widehat{mc}_{G,t} = \frac{Y_{PG}}{\theta Y_{OG}} \widehat{Y}_{OG,t} - \frac{Y_{PG}}{\theta Y_{OG}} \widehat{Y}_{PG,t}$$

$$\widehat{mc}_{G,t} = \Phi \left(\widehat{Y}_{OG,t} - \widehat{Y}_{PG,t} \right) \text{ where } \Phi = \frac{c_p}{(\theta-1)(1-c_p) - c_p}.$$

From (2.28) the real marginal cost (V) is a constant and hence $\widehat{mc}_{V,t} = 0$.

- **Derivation of the flexible price equilibrium:** The natural level of a variable is the flexible price equilibrium level. The natural level of the terms of trade in equation (2.52) and (2.53) can be derived as (for Equation (2.52))

$$
\begin{aligned}
T^n_{OGV,t} &= \frac{P_{OG,t}}{P_{V,t}} = \frac{\frac{MC_{G,t}}{mc_{G,t}}}{\frac{MC_{V,t}}{mc_{V,t}}} = \frac{\frac{W_t}{mc_{G,t}A_{G,t}}}{\frac{W_t}{mc_{G,t}A_{V,t}}} \\
&= \frac{mc_{V,t}}{mc_{G,t}}\frac{A_{V,t}}{A_{G,t}},
\end{aligned}
$$

where MC is nominal marginal cost and mc is real marginal cost.

$$
\begin{aligned}
\widehat{T}^n_{OGV,t} &= \widehat{mc}_{V,t} - \widehat{mc}_{G,t} + \widehat{A}_{V,t} - \widehat{A}_{G,t} \\
&= -\Phi(\widehat{Y}^n_{OG,t} - \widehat{Y}_{PG,t}) + \widehat{A}_{V,t} - \widehat{A}_{G,t}.
\end{aligned}
$$

Similarly $\widehat{T}^n_{AM,t}$ can be derived. For $\widehat{w}^n_t$ consider first the aggregate price index, P^n_t,

$$
\begin{aligned}
P^n_t &= \left(P^n_{A,t}\right)^{\delta}\left(P^n_{M,t}\right)^{1-\delta} = \left(P^n_{OG,t}\right)^{(1-\mu)\delta}\left(P^n_{V,t}\right)^{\mu\delta}\left(P^n_{M,t}\right)^{1-\delta} \\
&= \left(\frac{MC^n_{G,t}}{mc^n_{G,t}}\right)^{(1-\mu)\delta}\left(\frac{MC^n_{V,t}}{mc^n_{V,t}}\right)^{\mu\delta}\left(\frac{MC^n_{M,t}}{mc^n_{M,t}}\right)^{1-\delta} \\
&= \left(\frac{W^n_t}{A_{G,t}mc^n_{G,t}}\right)^{(1-\mu)\delta}\left(\frac{W^n_t}{A_{V,t}mc^n_{V,t}}\right)^{\mu\delta}\left(\frac{W^n_t}{A_{M,t}mc^n_{M,t}}\right)^{1-\delta} \\
&= \frac{W^n_t}{\left(A_{G,t}mc^n_{G,t}\right)^{(1-\mu)\delta}\left(A_{V,t}mc^n_{V,t}\right)^{\mu\delta}\left(A_{M,t}mc^n_{M,t}\right)^{1-\delta}} \\
&= \frac{W^n_t}{A_t\left(mc^n_{G,t}\right)^{(1-\mu)\delta}\left(mc^n_{V,t}\right)^{\mu\delta}\left(mc^n_{M,t}\right)^{1-\delta}}.
\end{aligned}
$$

$$
w^n_t = \frac{W^n_t}{P^n_t} = A_t\left(mc^n_{G,t}\right)^{(1-\mu)\delta}\left(mc^n_{V,t}\right)^{\mu\delta}\left(mc^n_{M,t}\right)^{1-\delta}.
$$

Note that $A_t = (A_{G,t})^{(1-\mu)\delta}(A_{V,t})^{\mu\delta}(A_{M,t})^{1-\delta}$. Log-linearizing this we get,

$$
\widehat{w}^n_t = \widehat{A}_t + \Phi(1-\mu)\delta(\widehat{Y}^n_{OG,t} - \widehat{Y}_{PG,t}).
$$

From the labor supply equation,

$$\widehat{w}_t^n = \psi \widehat{N}_t^n - (1-\sigma)\widehat{\Gamma}_t + \sigma \widehat{C}_t^n.$$

Substituting the value of $\widehat{N}_t^n = \Theta_1 \left[\widehat{C}_t^n - \widehat{A}_t + (1-\mu)(\gamma-1)\delta\left(\widehat{Y}_{OG,t}^n - \widehat{A}_{G,t}\right)\right] + \Theta_2\left(\widehat{Y}_{PG,t} - \widehat{A}_{G,t}\right)$ above we get,

$$\begin{aligned}\widehat{w}_t^n = \psi \Big[\Theta_1 \left[\widehat{C}_t^n - \widehat{A}_t + (1-\mu)(\gamma-1)\delta\left(\widehat{Y}_{OG,t}^n - \widehat{A}_{G,t}\right)\right] + \Theta_2\left(\widehat{Y}_{PG,t} - \widehat{A}_{G,t}\right)\Big] \\ - (1-\sigma)\widehat{\Gamma}_t + \sigma \widehat{C}_t^n.\end{aligned}$$

Replacing $\widehat{w}_t^n$ with $\widehat{A}_t + \Phi(1-\mu)\delta(\widehat{Y}_{OG,t}^n - \widehat{Y}_{PG,t})$ yields

$$\begin{aligned}\widehat{A}_t + \Phi(1-\mu)\delta(\widehat{Y}_{OG,t}^n - \widehat{Y}_{PG,t}) &= \psi\Theta_1 \left[\widehat{C}_t^n - \widehat{A}_t + (1-\mu)(\gamma-1)\delta\left(\widehat{Y}_{OG,t}^n - \widehat{A}_{G,t}\right)\right] \\ &\quad + \psi\Theta_2\left(\widehat{Y}_{PG,t} - \widehat{A}_{G,t}\right) - (1-\sigma)\widehat{\Gamma}_t + \sigma \widehat{C}_t^n.\end{aligned}$$

Rearranging this to get $\widehat{C}_t^n$, we get equation (2.56)

$$\begin{aligned}\widehat{C}_t^n &= \frac{(\psi\Theta_1+1)}{(\psi\Theta_1+\sigma)}\widehat{A}_t - \frac{(\Phi(1-\mu)\delta + \psi\Theta_2)}{(\psi\Theta_1+\sigma)}\widehat{Y}_{PG,t} + \frac{(1-\sigma)}{(\psi\Theta_1+\sigma)}\widehat{\Gamma}_t \\ &\quad + \frac{(\Phi(1-\mu)\delta - \psi\Theta_1(\gamma-1)(1-\mu)\delta)}{(\psi\Theta_1+\sigma)}\widehat{Y}_{OG,t}^n + \frac{(\psi\Theta_1(\gamma-1)(1-\mu)\delta + \psi\Theta_2)}{(\psi\Theta_1+\sigma)}\widehat{A}_{G,t}.\end{aligned}$$

- **Derivation of the sticky price equilibrium: equation** (2.59)

Using (2.41c) and (2.40) we get,

$$\widehat{mc}_{M,t} = \psi \widehat{N}_t + \sigma \widehat{C}_t - (1-\sigma)\widehat{\Gamma}_t - \widehat{A}_{M,t} + \delta \widehat{T}_{AM,t}.$$

Putting the value of $\widehat{N}_t$ from (2.45), we get

$$\begin{aligned}\widehat{mc}_{M,t} &= (\psi\Theta_1+\sigma)\,\widehat{C}_t - \psi\Theta_1\left[\widehat{A}_t - (1-\mu)(\gamma-1)\,\delta\left(\widehat{Y}_{OG,t}-\widehat{A}_{G,t}\right)\right] \\ &\quad +\psi\Theta_2\left(\widehat{Y}_{PG,t}-\widehat{A}_{G,t}\right) - (1-\sigma)\widehat{\Gamma}_t - \widehat{A}_{M,t} + \delta\widehat{T}_{AM,t}.\end{aligned}$$

At the natural level, $\widehat{mc}^n_{M,t} = 0$, which can also be written as,

$$\begin{aligned}0 &= (\psi\Theta_1+\sigma)\,\widehat{C}^n_t - \psi\Theta_1\left[\widehat{A}_t - (1-\mu)(\gamma-1)\,\delta\left(\widehat{Y}^n_{OG,t}-\widehat{A}_{G,t}\right)\right] \\ &\quad +\psi\Theta_2\left(\widehat{Y}_{PG,t}-\widehat{A}_{G,t}\right) - (1-\sigma)\widehat{\Gamma}_t - \widehat{A}_{M,t} + \delta\widehat{T}^n_{AM,t} \\ \widetilde{mc}_{M,t} &= \widehat{mc}_{M,t} - \widehat{mc}^n_{M,t} = (\psi\Theta_1+\sigma)\left(\widehat{C}_t-\widehat{C}^n_t\right) + \delta\left(\widehat{T}_{AM,t}-\widehat{T}^n_{AM,t}\right) \\ \widehat{mc}_{M,t} &= (\psi\Theta_1+\sigma)\,\widetilde{C}_t + \delta\widetilde{T}_{AM,t}\end{aligned}$$

Using demand functions, $\widetilde{C}_t = \widetilde{Y}_{M,t} - \delta\widetilde{T}_{AM,t}$, the above equation can be written as,

$$\widehat{mc}_{M,t} = (\psi\Theta_1+\sigma)\,\widetilde{Y}_{M,t} - \delta\,(\psi\Theta_1+\sigma-1)\,\widetilde{T}_{AM,t}.$$

Appendix B

Technical Appendix: Chapter 3

B.1 Derivation of the welfare loss function

The average utility flow at time t, is defined as

$$w_t = U\left(C_t\right) - \frac{1}{\delta\left(1-\mu\right)} \int_{0}^{\delta(1-\mu)} v(N_{G,t}\left(i\right))di - \frac{1}{\delta\mu} \int_{\delta(1-\mu)}^{\delta} v(N_{V,t}\left(i\right))di - \frac{1}{\left(1-\delta\right)} \int_{\delta}^{1} v(N_{M,t}\left(i\right))di$$

where $U\left(C_t\right)$ is the utility from the aggregate consumption bundle C_t and $v(N_t\left(i\right))$ is the disutility of supplying labor $N_t\left(i\right)$ by the i^{th} household. The sum of lifetime welfare function becomes

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{w_t - w}{U_C\ C}\right) \tag{B.1}$$

Alternatively, the welfare loss function is

$$W_t = -E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{w_t - w}{U_C\ C}\right) \tag{B.2}$$

We take a second order approximation to $U(C_t,)$,

$$U(C_t,) \approx U_c\, C\left(\frac{C_t - C}{C}\right) + U_{cc}\, C^2 \left(\frac{C_t - C}{C}\right)^2$$

using $\frac{Z_t - Z}{Z} \approx \widehat{Z}_t + \frac{1}{2}\widehat{Z}_t^2$ where $\widehat{Z}_t = \ln Z_t - \ln Z$

$$U(C_t,) \approx U_c\, C\left(\widehat{C}_t + \frac{1}{2}\widehat{C}_t^2\right) + \frac{1}{2}U_{cc}C^2\left(\widehat{C}_t + \frac{1}{2}\widehat{C}_t^2\right)^2$$

$$U(C_t,) \approx U_c\, C\left(\widehat{C}_t + \frac{1}{2}\widehat{C}_t^2\right) + \frac{1}{2}U_{cc}C^2\widehat{C}_t^2 + \|O\|^3$$

using $\sigma = -\frac{U_{cc}}{U_c}C$

$$U(C_t,) \approx U_c\, C\left[\widehat{C}_t + \frac{1}{2}(1-\sigma)\widehat{C}_t^2\right] + \|O\|^3 \tag{B.3}$$

Now we take the second order approximation to disutility of labor, $v(N_{V,t}(i))$.This can be rewritten as $V(Y_{V,t}(i), A_{V,t})$, since $Y_{V,t}(i) = A_{V,t}N_{V,t}(i)$. Similarly $v(N_{M,t}(i))$ and $v(N_{G,t}(i))$ can be rewritten as $V(Y_{M,t}(i), A_{M,t})$ and $V(Y_{OG,t}(i), Y_{PG,t}, A_{G,t})$ respectively. Consider a second order approximation to $v(N_{V,t}(i))$,

$$\begin{aligned} V(Y_{V,t}(i), A_{V,t}) &\approx V(Y_V, A_V) + V_{Y_V}(Y_{V,t}(i) - Y_V) + V_{A_V}(A_{V,t} - A_V) + \frac{V_{A_V A_V}}{2}(A_{V,t} - A_V)^2 \\ &\quad + V_{Y_V A_V}(Y_{V,t}(i) - Y_V)(A_{V,t} - A_V) + \frac{V_{Y_V Y_V}}{2}(Y_{V,t}(i) - Y_V)^2 + \|O\|^3 \end{aligned}$$

$$\begin{aligned} V(Y_{V,t}(i), A_{V,t}) &\approx V_{Y_V}Y_V\left(\widehat{Y}_{V,t}(i) + \frac{1}{2}\left(\widehat{Y}_{V,t}(i)\right)^2\right) + V_{A_V}A_V\left(\widehat{A}_{V,t} + \frac{1}{2}\left(\widehat{A}_{V,t}\right)^2\right) \\ &\quad + V_{Y_V A_V}Y_V A_V\left(\widehat{Y}_{V,t}(i) + \frac{1}{2}\left(\widehat{Y}_{V,t}(i)\right)^2\right)\left(\widehat{A}_{V,t} + \frac{1}{2}\left(\widehat{A}_{V,t}\right)^2\right) \\ &\quad + \frac{V_{Y_V Y_V}}{2}Y_V Y_V\left(\widehat{Y}_{V,t}(i) + \frac{1}{2}\left(\widehat{Y}_{V,t}(i)\right)^2\right)^2 \\ &\quad + \frac{V_{A_V A_V}}{2}A_V A_V\left(\widehat{A}_{V,t} + \frac{1}{2}\left(\widehat{A}_{V,t}\right)^2\right)^2 + \|O\|^3 + t.i.p. \end{aligned}$$

$$V\left(Y_{V,t}(i),A_{V,t}\right) \approx V_{Y_V}Y_V\left(\widehat{Y}_{V,t}(i)+\frac{1}{2}\left(\widehat{Y}_{V,t}(i)\right)^2\right)+V_{Y_VA_V}Y_VA_V\left(\widehat{Y}_{V,t}(i)\widehat{A}_{V,t}\right)$$
$$+\frac{V_{Y_VY_V}}{2}Y_VY_V\left(\widehat{Y}_{V,t}(i)\right)^2+\|O\|^3+t.i.p.$$

Assuming the steady state value of shocks is 1, i.e., $A_V = A_G = A_M = 1$ and let $g_{V,t} = -\frac{V_{Y_VA_V}\widehat{A}_{V,t}}{V_{Y_VY_V}Y_V}$

$$V\left(Y_{V,t}(i),A_{V,t}\right) \approx V_{Y_V}Y_V\left(\widehat{Y}_{V,t}(i)+\frac{1}{2}\left(\widehat{Y}_{V,t}(i)\right)^2\right)-g_{V,t}V_{Y_VY_V}Y_VY_V\left(\widehat{Y}_{V,t}(i)\right)$$
$$+\frac{V_{Y_VY_V}}{2}Y_VY_V\left(\widehat{Y}_{V,t}(i)\right)^2+\|O\|^3+t.i.p.$$

Using $V_{Y_VY_V} = \psi\frac{V_{Y_V}}{Y_V}$

$$V\left(Y_{V,t}(i),A_{V,t}\right) \approx V_{Y_V}Y_V\left[\widehat{Y}_{V,t}(i)-\psi g_{V,t}\left(\widehat{Y}_{V,t}(i)\right)+\left(\frac{\psi+1}{2}\right)\left(\widehat{Y}_{V,t}(i)\right)^2\right]+\|O\|^3+t.i.p. \tag{B.4}$$

Similarly for the manufacturing sector,

$$V\left(Y_{M,t}(i),A_{M,t}\right) \approx V_{Y_M}Y_M\left[\widehat{Y}_{M,t}(i)-\psi g_{M,t}\left(\widehat{Y}_{M,t}(i)\right)+\left(\frac{\psi+1}{2}\right)\left(\widehat{Y}_{M,t}(i)\right)^2\right]+\|O\|^3+t.i.p. \tag{B.5}$$

where $g_{M,t} = -\frac{V_{Y_MA_M}\widehat{A}_{M,t}}{V_{Y_MY_M}Y_M}$. For the grain sector, consider a second order approximation to $v\left(N_{G,t}(i)\right)$, since $Y_{G,t}(i) = Y_{OG}(i)+Y_{PG,t} = A_{G,t}N_{G,t}(i)$. This implies

$$V\left(Y_{OG,t}(i),Y_{PG,t},A_{G,t}\right) \approx V\left(Y_{OG},Y_{PG,t},A_G\right)+V_{Y_{OG}}\left(Y_{OG,t}(i)-Y_{OG}\right)+V_{Y_{PG}}\left(Y_{PG,t}-Y_{PG}\right)$$
$$+V_{A_G}\left(A_{G,t}-A_G\right)+V_{Y_{OG}A_G}\left(Y_{OG,t}(i)-Y_{OG}\right)\left(A_{G,t}-A_G\right)$$
$$+V_{Y_{PG}A_G}\left(Y_{PG,t}-Y_{PG,t}\right)\left(A_{G,t}-A_G\right)+\frac{V_{A_GA_G}}{2}\left(A_{G,t}-A_G\right)^2$$
$$+V_{Y_{OG}Y_{PG}}\left(Y_{OG,t}(i)-Y_{OG}\right)\left(Y_{PG,t}-Y_{PG,t}\right)+\frac{V_{Y_{OG}Y_{OG}}}{2}\left(Y_{OG,t}(i)-Y_{OG}\right)^2$$
$$+\frac{V_{Y_{PG}Y_{PG}}}{2}\left(Y_{PG,t}-Y_{PG,t}\right)^2+\|O\|^3$$

$$
\begin{aligned}
V\left(Y_{OG,t}(i),Y_{PG,t},A_{G,t}\right) \;\approx\;& V_{Y_{OG}}Y_{OG}\left(\widehat{Y}_{OG,t}\left(i\right)+\frac{1}{2}\left(\widehat{Y}_{OG,t}\left(i\right)\right)^{2}\right)+\frac{V_{Y_{OG}Y_{OG}}}{2}Y_{OG}Y_{OG}\left(\widehat{Y}_{OG,t}\left(i\right)\right)^{2}\\
&+V_{Y_{OG}A_{G}}Y_{OG}A_{G}\left(\widehat{Y}_{OG,t}\left(i\right)\widehat{A}_{G,t}\right)+V_{Y_{OG}Y_{PG}}Y_{OG}Y_{PG}\left(\widehat{Y}_{OG,t}\left(i\right)\widehat{Y}_{PG,t}\right)\\
&+\left\|O\right\|^{3}+t.i.p.
\end{aligned}
$$

Assuming the steady state value of shocks is 1, i.e., $A_V = A_G = A_M = 1$ and let $g_{OG,t} = -\frac{V_{Y_{OG}A_G}\widehat{A}_{G,t}}{V_{Y_{OG}Y_{OG}}Y_{OG}}$ and $g_{PG,t} = -\widehat{Y}_{PG,t}$

$$
\begin{aligned}
V\left(Y_{OG,t}(i),Y_{PG,t},A_{G,t}\right) \;\approx\;& V_{Y_{OG}}Y_{OG}\left(\widehat{Y}_{OG,t}\left(i\right)+\frac{1}{2}\left(\widehat{Y}_{OG,t}\left(i\right)\right)^{2}\right)+\frac{V_{Y_{OG}Y_{OG}}}{2}Y_{OG}Y_{OG}\left(\widehat{Y}_{OG,t}\left(i\right)\right)^{2}\\
&-g_{OG,t}V_{Y_{OG}Y_{OG}}Y_{OG}Y_{OG}\widehat{Y}_{OG,t}\left(i\right)-g_{PG,t}V_{Y_{OG}Y_{OG}}Y_{OG}Y_{PG}\widehat{Y}_{OG,t}\left(i\right)\\
&+\left\|O\right\|^{3}+t.i.p.
\end{aligned}
$$

Using $V_{Y_{OG}Y_{OG}} = \psi\frac{V_{Y_{OG}}}{Y_G} = \psi\frac{V_{Y_{OG}}}{Y_{OG}+Y_{PG,t}}$

$$
\begin{aligned}
V\left(Y_{OG,t}(i),Y_{PG,t},A_{G,t}\right) \;\approx\;& V_{Y_{OG}}Y_{OG}[\widehat{Y}_{OG,t}\left(i\right)+\frac{1}{2}\left(\widehat{Y}_{OG,t}\left(i\right)\right)^{2}+\psi\frac{Y_{OG}}{2\left(Y_{OG}+Y_{PG,t}\right)}\left(\widehat{Y}_{OG,t}\left(i\right)\right)^{2}\\
&-g_{OG,t}\psi\frac{Y_{OG}}{Y_{OG}+Y_{PG}}\widehat{Y}_{OG,t}\left(i\right)-g_{PG,t}\psi\frac{Y_{PG}}{Y_{OG}+Y_{PG}}\widehat{Y}_{OG,t}\left(i\right)]+\left\|O\right\|^{3}+t.i.p.
\end{aligned}
$$

Since $c_p = \frac{Y_{PG}}{Y_{PG}+Y_{OG}}$,

$$
\begin{aligned}
V\left(Y_{OG,t}(i),Y_{PG,t},A_{G,t}\right) \;\approx\;& V_{Y_{OG}}Y_{OG}[\widehat{Y}_{OG,t}\left(i\right)+\left(\frac{1+\psi\left(1-c_p\right)}{2}\right)\left(\widehat{Y}_{OG,t}\left(i\right)\right)^{2}\\
&-\psi\left(g_{OG,t}\left(1-c_p\right)+g_{PG,t}c_p\right)\widehat{Y}_{OG,t}\left(i\right)]+\left\|O\right\|^{3}+t.i.p.
\end{aligned}
\tag{B.6}
$$

Let

$$
\overline{V}_t = \frac{1}{\delta\left(1-\mu\right)}\int_0^{\delta(1-\mu)} v(N_{G,t}\left(i\right))di+\frac{1}{\delta\mu}\int_{\delta(1-\mu)}^{\delta} v(N_{V,t}\left(i\right))di+\frac{1}{\left(1-\delta\right)}\int_{\delta\mu}^{1} v(N_{M,t}\left(i\right))di
$$

$$
=\frac{1}{\delta\left(1-\mu\right)}\int_0^{\delta(1-\mu)} V\left(Y_{OG,t}(i),A_{G,t}\right)di+\frac{1}{\delta\mu}\int_{\delta(1-\mu)}^{\delta} V\left(Y_{V,t}(i),A_{V,t}\right)di+\frac{1}{\left(1-\delta\right)}\int_{\delta}^{1} V\left(Y_{M,t}(i),A_{M,t}\right)di
$$

Putting values from equations $(B.4)$, $(B.5)$ and $(B.6)$, we get

$$\begin{aligned}
\overline{V}_t \approx\ & \frac{1}{\delta(1-\mu)} \int_0^{\delta(1-\mu)} V_{Y_{OG}} Y_{OG} \left[\widehat{Y}_{OG,t}(i) + \left(\frac{1+\psi(1-c_p)}{2} \right) \left(\widehat{Y}_{OG,t}(i) \right)^2 - \right. \\
& \left. \psi \left(g_{OG,t}(1-c_p) + g_{PG,t} c_p \right) \widehat{Y}_{OG,t}(i) \right] di \\
& + \frac{1}{\delta\mu} \int_{\delta(1-\mu)}^{\delta} V_{Y_V} Y_V \left[\widehat{Y}_{V,t}(i) - \psi g_{V,t} \left(\widehat{Y}_{V,t}(i) \right) + \left(\frac{\psi+1}{2} \right) \left(\widehat{Y}_{V,t}(i) \right)^2 \right] di \\
& + \frac{1}{(1-\delta)} \int_{\delta}^{1} V_{Y_M} Y_M \left[\widehat{Y}_{M,t}(i) - \psi g_{M,t} \left(\widehat{Y}_{M,t}(i) \right) + \left(\frac{\psi+1}{2} \right) \left(\widehat{Y}_{M,t}(i) \right)^2 \right] di \\
& + \|O\|^3 + t.i.p.
\end{aligned}$$

Aggregating disutility over all households,

$$\begin{aligned}
\overline{V}_t \approx\ & V_{Y_V} Y_V \left[E_i \left\{ \widehat{Y}_{V,t}(i) \right\} - \psi g_{V,t} E_i \left\{ \widehat{Y}_{V,t}(i) \right\} + \left(\frac{\psi+1}{2} \right) E_i \left\{ \widehat{Y}_{V,t}(i)^2 \right\} \right] \\
& + V_{Y_M} Y_M \left[E_i \left\{ \widehat{Y}_{M,t}(i) \right\} - \psi g_{M,t} E_i \left\{ \widehat{Y}_{M,t}(i) \right\} + \left(\frac{\psi+1}{2} \right) E_i \left\{ \widehat{Y}_{M,t}(i)^2 \right\} \right] \\
& + V_{Y_{OG}} Y_{OG} \left[E_i \left\{ \widehat{Y}_{OG,t}(i) \right\} + \left(\frac{1+\psi(1-c_p)}{2} \right) E_i \left\{ \widehat{Y}_{OG,t}(i)^2 \right\} \right. \\
& \left. - \psi \left(g_{OG,t}(1-c_p) + g_{PG,t} c_p \right) E_i \left\{ \widehat{Y}_{OG,t}(i) \right\} \right] \\
& + \|O\|^3 + t.i.p.
\end{aligned}$$

Since $Var\left(X\right)=E\left(X^2\right)-\left(E\left(X\right)\right)^2$

$$\begin{aligned}\overline{V}_t \approx\ & V_{Y_V}Y_V\left[\left(1-\psi g_{V,t}\right)E_i\left\{\widehat{Y}_{V,t}\left(i\right)\right\}+\left(\frac{\psi+1}{2}\right)\left[Var\left\{\widehat{Y}_{V,t}\left(i\right)\right\}\right.\right.\\ & \left.\left.+\left[E_i\left\{\widehat{Y}_{V,t}\left(i\right)\right\}\right]^2\right]\right]+V_{Y_M}Y_M\left[\left(1-\psi g_{M,t}\right)E_i\left\{\widehat{Y}_{M,t}\left(i\right)\right\}\right.\\ & \left.+\left(\frac{\psi+1}{2}\right)\left[Var\left\{\widehat{Y}_{M,t}\left(i\right)\right\}+\left[E_i\left\{\widehat{Y}_{M,t}\left(i\right)\right\}\right]^2\right]\right]\\ & +V_{Y_{OG}}Y_{OG}\left[\left(1-\psi\left(g_{OG,t}\left(1-c_p\right)+g_{PG,t}c_p\right)\right)E_i\left\{\widehat{Y}_{OG,t}\left(i\right)\right\}\right.\\ & \left.+\left(\frac{1+\psi\left(1-c_p\right)}{2}\right)\left[Var\left\{\widehat{Y}_{OG,t}\left(i\right)\right\}+\left[E_i\left\{\widehat{Y}_{OG,t}\left(i\right)\right\}\right]^2\right]\right]\\ & +\left\|O\right\|^3+t.i.p.\end{aligned}$$

It can be shown that (see Woodford (2003) and Gali and Monacelli (2005)),

$$\begin{aligned}\widehat{Y}_{V,t} &= E_i\left\{\widehat{Y}_{V,t}\left(i\right)\right\}+\frac{1}{2}\left(\frac{\theta-1}{\theta}\right)Var\left\{\widehat{Y}_{V,t}\left(i\right)\right\}\\ \widehat{Y}_{M,t} &= E_i\left\{\widehat{Y}_{M,t}\left(i\right)\right\}+\frac{1}{2}\left(\frac{\theta-1}{\theta}\right)Var\left\{\widehat{Y}_{M,t}\left(i\right)\right\}\\ \widehat{Y}_{OG,t} &= E_i\left\{\widehat{Y}_{OG,t}\left(i\right)\right\}+\frac{1}{2}\left(\frac{\theta-1}{\theta}\right)Var\left\{\widehat{Y}_{OG,t}\left(i\right)\right\}\end{aligned}$$

Therefore

$$\begin{aligned}\overline{V}_t \approx\ & V_{Y_V}Y_V\left[\left(1-\psi g_{V,t}\right)\left[\widehat{Y}_{V,t}-\frac{1}{2}\left(\frac{\theta-1}{\theta}\right)Var\left\{\widehat{Y}_{V,t}\left(i\right)\right\}\right]+\left(\frac{\psi+1}{2}\right)\left[Var\left\{\widehat{Y}_{V,t}\left(i\right)\right\}\right.\right.\\ & \left.\left.+\widehat{Y}_{V,t}^2\right]\right]+V_{Y_M}Y_M\left[\left(1-\psi g_{M,t}\right)\left[\widehat{Y}_{M,t}-\frac{1}{2}\left(\frac{\theta-1}{\theta}\right)Var\left\{\widehat{Y}_{M,t}\left(i\right)\right\}\right]\right.\\ & \left.+\left(\frac{\psi+1}{2}\right)\left[Var\left\{\widehat{Y}_{M,t}\left(i\right)\right\}+\widehat{Y}_{M,t}^2\right]\right]\\ & +V_{Y_{OG}}Y_{OG}\left[\left(1-\psi\left(g_{OG,t}\left(1-c_p\right)+g_{PG,t}c_p\right)\right)\left[\widehat{Y}_{OG,t}-\frac{1}{2}\left(\frac{\theta-1}{\theta}\right)Var\left\{\widehat{Y}_{OG,t}\left(i\right)\right\}\right]\right.\\ & \left.+\left(\frac{1+\psi\left(1-c_p\right)}{2}\right)\left[Var\left\{\widehat{Y}_{OG,t}\left(i\right)\right\}+\widehat{Y}_{OG,t}^2\right]\right]+\left\|O\right\|^3+t.i.p.\end{aligned}$$

Using a result in Woodford (2003), since the manufacturing sector has sticky prices in place,

$$Var\left\{\widehat{Y}_{M,t}\left(i\right)\right\} = \theta^{2}Var\left\{\widehat{P}_{M,t}\left(i\right)\right\}.$$

Similarly for the grain and vegetable sectors, which are flexible price sectors,

$$\begin{aligned} Var\left\{\widehat{Y}_{V,t}\left(i\right)\right\} &= \theta^{2}Var\left\{\widehat{P}_{V,t}\left(i\right)\right\} = 0 \\ Var\left\{\widehat{Y}_{OG,t}\left(i\right)\right\} &= \theta^{2}Var\left\{\widehat{P}_{OG,t}\left(i\right)\right\} = 0 \end{aligned}$$

On simplifying we get,

$$\begin{aligned} \overline{V}_{t} \approx\ & V_{Y_V}Y_V\left[\widehat{Y}_{V,t} - \psi g_{V,t}\widehat{Y}_{V,t} + \left(\frac{\psi+1}{2}\right)\widehat{Y}_{V,t}^{2}\right] \\ & + V_{Y_M}Y_M\left[\widehat{Y}_{M,t} - \psi g_{M,t}\widehat{Y}_{M,t} + \frac{1}{2}\left(\theta^{-1}+\psi\right)\theta^{2}Var\left\{\widehat{P}_{M,t}\left(i\right)\right\}\right. \\ & \left. + \left(\frac{\psi+1}{2}\right)\widehat{Y}_{M,t}^{2}\right] + V_{Y_{OG}}Y_{OG}\left[\widehat{Y}_{OG,t} - \psi\left(g_{OG,t}\left(1-c_p\right) + g_{PG,t}c_p\right)\widehat{Y}_{OG,t}\right. \\ & \left. + \left(\frac{1+\psi\left(1-c_p\right)}{2}\right)\widehat{Y}_{OG,t}^{2}\right] + \left\|O\right\|^{3} + t.i.p. \end{aligned} \tag{B.7}$$

From the first order condition of the consumption-leisure choice at steady state,

$$\frac{V_{Y_G}}{U_C} = \frac{V_{Y_V}}{U_C} = \frac{V_{Y_M}}{U_C} = \frac{W}{P}$$

Note here $P = P_A^{\delta}P_M^{1-\delta} = P_{OG}^{(1-\mu)\delta}P_V^{\mu\delta}P_M^{1-\delta}$. Using Section 2.3.2 and the Technical Appendix A.3 of Chapter 2,

$$P_A = \frac{\theta\left(1-c_p\right)}{\left(\theta-1\right)\left(1-c_p\right)-c_p}W;\ P_M = P_V = \frac{\theta}{\theta-1}W$$

$$P = \gamma^{-(1-\mu)\delta}\left(\frac{\theta-1}{\theta}\right)W$$

We assume that government provides an employment subsidy, $(1-\tau)$, to do away with the inefficiency due to monopolistic competition. Here $(1-\tau)=\frac{\theta-1}{\theta}$. This implies,

$$\frac{V_{Y_G}}{U_C}=\frac{V_{Y_V}}{U_C}=\frac{V_{Y_M}}{U_C}=\gamma^{(1-\mu)\delta}$$

The steady state in a goods market equilibrium implies, $Y_{OG}=C_{OG}$, $Y_V=C_V$ and $Y_M=C_M$. Equation $(B.7)$ reduces to,

$$\begin{aligned}\overline{V}_t \approx\ & U_C\gamma^{(1-\mu)\delta}C_V\left[\widehat{Y}_{V,t}-\psi g_{V,t}\widehat{Y}_{V,t}+\left(\frac{\psi+1}{2}\right)\widehat{Y}^2_{V,t}\right] \\ & +U_C\gamma^{(1-\mu)\delta}C_M\left[\widehat{Y}_{M,t}-\psi g_{M,t}\widehat{Y}_{M,t}+\frac{1}{2}\left(\theta^{-1}+\psi\right)\theta^2 Var\left\{\widehat{P}_{M,t}(i)\right\}\right. \\ & \left.+\left(\frac{\psi+1}{2}\right)\widehat{Y}^2_{M,t}\right]+U_C\gamma^{(1-\mu)\delta}C_{OG}\left[\widehat{Y}_{OG,t}-\psi\left(g_{OG,t}\left(1-c_p\right)+g_{PG,t}c_p\right)\widehat{Y}_{OG,t}\right. \\ & \left.+\left(\frac{1+\psi\left(1-c_p\right)}{2}\right)\widehat{Y}^2_{OG,t}\right]+\|O\|^3+t.i.p. \qquad \text{(B.8)}\end{aligned}$$

Again using the Technical Appendix A.3 of Chapter 2,

$$\begin{aligned}\frac{C_M}{C} &= (1-\delta)\,\gamma^{-(1-\mu)\delta} \\ \frac{C_V}{C} &= \mu\delta\gamma^{-(1-\mu)\delta} \\ \frac{C_{OG}}{C} &= (1-\mu)\,\delta\gamma^{-(1-\mu)\delta+1}\end{aligned}$$

Replacing Y_M, Y_V, Y_{OG} and V_Y in equation$(B.7)$ with C_M, C_V, C_{OG} and $U_C\ \gamma^{(1-\mu)\delta}$ respectively we get,

$$\begin{aligned}\overline{V}_t &\approx U_C\ C\left[\mu\delta\left[\widehat{Y}_{V,t} - \psi g_{V,t}\widehat{Y}_{V,t} + \left(\frac{\psi+1}{2}\right)\widehat{Y}^2_{V,t}\right]\right. \\ &\quad + (1-\delta)\left[\widehat{Y}_{M,t} - \psi g_{M,t}\widehat{Y}_{M,t} + \frac{1}{2}\left(\theta^{-1}+\psi\right)\theta^2 Var\left\{\widehat{P}_{M,t}(i)\right\}\right. \\ &\quad \left. + \left(\frac{\psi+1}{2}\right)\widehat{Y}^2_{M,t}\right] + (1-\mu)\delta\gamma\left[\widehat{Y}_{OG,t} - \psi\left(g_{OG,t}(1-c_p) + g_{PG,t}c_p\right)\widehat{Y}_{OG,t}\right. \\ &\quad \left.\left. + \left(\frac{1+\psi(1-c_p)}{2}\right)\widehat{Y}^2_{OG,t}\right]\right] + \|O\|^3 + t.i.p.\end{aligned} \tag{B.9}$$

Now, we know that

$$w_t = U(C_t) - \overline{V}_t$$

Now, combining the second order approximation of utility from consumption (equation $(B.3)$) and the second order approximation of aggregated disutility from the labour supply (equation $(B.9)$) in the average utility function (equation (3.1)), and using $\mu\delta\widehat{Y}_{V,t} + (1-\delta)\widehat{Y}_{M,t} + (1-\mu)\delta\widehat{Y}_{OG,t} = \widehat{C}_t$ we get,

$$\begin{aligned}w_t &\approx U_C\ C\left[\widehat{C}_t + \frac{1}{2}(1-\sigma)\widehat{C}^2_t - \widehat{C}_t + (1-\mu)\delta(1-\gamma)\widehat{Y}_{OG,t} + \mu\delta\psi g_{V,t}\widehat{Y}_{V,t}\right. \\ &\quad -\mu\delta\left(\frac{\psi+1}{2}\right)\widehat{Y}^2_{V,t} + (1-\delta)\psi g_{M,t}\widehat{Y}_{M,t} - \frac{1}{2}(1-\delta)\left(\theta^{-1}+\psi\right)\theta^2 Var\left\{\widehat{P}_{M,t}(i)\right\} \\ &\quad -(1-\delta)\left(\frac{\psi+1}{2}\right)\widehat{Y}^2_{M,t} + (1-\mu)\delta\gamma\psi\left(g_{OG,t}(1-c_p) - g_{PG,t}c_p\right)\widehat{Y}_{OG,t} \\ &\quad \left. -(1-\mu)\delta\gamma\left(\frac{1+\psi(1-c_p)}{2}\right)\widehat{Y}^2_{OG,t}\right] + \|O\|^3 + t.i.p.\end{aligned} \tag{B.10}$$

Simplifying further, we get

$$\begin{aligned}w_t &\approx U_C\ C\left[\frac{1}{2}(1-\sigma)\widehat{C}^2_t + \alpha_{1V}\widehat{Y}_{V,t} - \alpha_{2V}\widehat{Y}^2_{V,t}\right. \\ &\quad +\alpha_{1M}\widehat{Y}_{M,t} - \frac{1}{2}(1-\delta)\left(\theta^{-1}+\psi\right)\theta^2 Var\left\{\widehat{P}_{M,t}(i)\right\} - \alpha_{2M}\widehat{Y}^2_{M,t} \\ &\quad \left. +\alpha_{1G}\widehat{Y}_{OG,t} - \alpha_{2G}\widehat{Y}^2_{OG,t}\right] + \|O\|^3 + t.i.p.\end{aligned}$$

where,

$$\alpha_{1V} \text{ (coefficient of } \widehat{Y}_{V,t}) = \mu\delta\psi g_{V,t} \quad (B.11)$$

$$\alpha_{2V} \text{ (coefficient of } \widehat{Y}_{V,t}^2) = \mu\delta\left(\frac{\psi+1}{2}\right) \quad (B.12)$$

$$\alpha_{1M} \text{ (coefficient of } \widehat{Y}_{M,t}) = (1-\delta)\psi g_{M,t} \quad (B.13)$$

$$\alpha_{2M} \text{ (coefficient of } \widehat{Y}_{M,t}^2) = (1-\delta)\left(\frac{\psi+1}{2}\right) \quad (B.14)$$

$$\alpha_{1G} \text{ (coefficient of } \widehat{Y}_{OG,t}) = (1-\mu)\delta\left(\gamma\psi\left(g_{OG,t}(1-c_p) - g_{PG,t}c_p\right) + (1-\gamma)\right) \quad (B.15)$$

$$\alpha_{2G} \text{ (coefficient of } \widehat{Y}_{OG,t}^2) = (1-\mu)\delta\gamma\left(\frac{1+\psi(1-c_p)}{2}\right) \quad (B.16)$$

Now substituting,

$$\widehat{Y}_{M,t} = \widehat{C}_t + \delta\widehat{T}_{AM,t} \quad (B.17)$$

$$\widehat{Y}_{V,t} = \widehat{C}_t - (1-\delta)\widehat{T}_{AM,t} + (1-\mu)\widehat{T}_{OGV,t}$$

$$\widehat{Y}_{OG,t} = \widehat{C}_t - (1-\delta)\widehat{T}_{AM,t} - \mu\widehat{T}_{OGV,t}$$

$$\begin{aligned} w_t \approx\; & U_C\, C\left[\frac{1}{2}(1-\sigma)\widehat{C}_t^2 - \frac{1}{2}(1-\delta)\left(\theta^{-1}+\psi\right)\theta^2 Var\left\{\widehat{P}_{M,t}(i)\right\}\right. \\ & + (\alpha_{1V}+\alpha_{1M}+\alpha_{1G})\widehat{C}_t + (\alpha_{1M}\delta - \alpha_{1V}(1-\delta) - \alpha_{1G}(1-\delta))\widehat{T}_{AM,t} \\ & + (\alpha_{1V}(1-\mu) - \alpha_{1G}\mu)\widehat{T}_{OGV,t} - (\alpha_{2V}+\alpha_{2M}+\alpha_{2G})\widehat{C}_t^2 - \left[\alpha_{2M}\delta^2 + \alpha_{2V}(1-\delta)^2\right. \\ & \left. +\alpha_{2G}(1-\delta)^2\right]\widehat{T}_{AM,t}^2 - \left(\alpha_{2V}(1-\mu)^2 + \alpha_{2G}\mu^2\right)\widehat{T}_{OGV,t}^2 \\ & - (2\alpha_{2M}\delta - 2\alpha_{2V}(1-\delta) - 2\alpha_{2G}(1-\delta))\widehat{C}_t\widehat{T}_{AM,t} \\ & \left. - (2\alpha_{2V}(1-\mu) - 2\alpha_{2G}\mu)\widehat{C}_t\widehat{T}_{OGV,t} - (2\alpha_{2G}(1-\delta)\mu - 2\alpha_{2V}(1-\delta)(1-\mu))\widehat{T}_{AM,t}\widehat{T}_{OGV,t}\right] \\ & + \|O\|^3 + t.i.p. \end{aligned}$$

Now we use the fact that $\widehat{Y}_{OG,t}$, $\widehat{T}_{OGV,t}$, $\widehat{Y}_{V,t}$, are $t.i.p.$ as they are natural levels.

$$\begin{aligned}
\widehat{C}_t\widehat{T}_{AM,t} &= \left(\widehat{Y}_{V,t} + (1-\delta)\,\widehat{T}_{AM,t} - (1-\mu)\,\widehat{T}_{OGV,t}\right)\widehat{T}_{AM,t} \\
&= \widehat{Y}_{V,t}\widehat{T}_{AM,t} + (1-\delta)\,\widehat{T}_{AM,t}^2 - (1-\mu)\,\widehat{T}_{OGV,t}\widehat{T}_{AM,t}
\end{aligned}$$

$$\begin{aligned}
w_t \approx\ & U_C C\left[-\frac{1}{2}(1-\delta)\left(\theta^{-1}+\psi\right)\theta^2 Var\left\{\widehat{P}_{M,t}(i)\right\}\right. \\
& +\left[(\alpha_{1V}+\alpha_{1M}+\alpha_{1G}) - (2\alpha_{2V}(1-\mu) - 2\alpha_{2G}\mu)\,\widehat{T}_{OGV,t}\right]\widehat{C}_t + [(\alpha_{1M}\delta - \alpha_{1V}(1-\delta) \\
& -\alpha_{1G}(1-\delta)) - (2\alpha_{2M}\delta - 2\alpha_{2V}(1-\delta) - 2\alpha_{2G}(1-\delta))\left(\widehat{Y}_{V,t} - (1-\mu)\,\widehat{T}_{OGV,t}\right) \\
& \left.-(2\alpha_{2G}(1-\delta)\mu - 2\alpha_{2V}(1-\delta)(1-\mu))\,\widehat{T}_{OGV,t}\right]\widehat{T}_{AM,t} + (\alpha_{1V}(1-\mu) - \alpha_{1G}\mu)\,\widehat{T}_{OGV,t} - \\
& \left[-\frac{1}{2}(1-\sigma) + (\alpha_{2V}+\alpha_{2M}+\alpha_{2G})\right]\widehat{C}_t^2 - \left[\left(\alpha_{2M}\delta^2 + \alpha_{2V}(1-\delta)^2 + \alpha_{2G}(1-\delta)^2\right)\right. \\
& \left.+(1-\delta)(2\alpha_{2M}\delta - 2\alpha_{2V}(1-\delta) - 2\alpha_{2G}(1-\delta))\right]\widehat{T}_{AM,t}^2 - \left(\alpha_{2V}(1-\mu)^2 + \alpha_{2G}\mu^2\right)\widehat{T}_{OGV,t}^2\Big] \\
& + \|O\|^3 + t.i.p.
\end{aligned}$$

$$\begin{aligned}
w_t \approx\ & U_C\ C\left[-\frac{1}{2}(1-\delta)\left(\theta^{-1}+\psi\right)\theta^2 Var\left\{\widehat{P}_{M,t}(i)\right\} + \beta_{1C}\widehat{C}_t\right. \\
& \left.+\beta_{ITAM}\widehat{T}_{AM,t} + \beta_{1TOGV}\widehat{T}_{OGV,t} - \beta_{2C}\widehat{C}_t^2 - \beta_{2TAM}\widehat{T}_{AM,t}^2 - \beta_{2TOGV}\widehat{T}_{OGV,t}^2\right] \\
& + \|O\|^3 + t.i.p.
\end{aligned}$$

where,

$$\beta_{1C} \text{ (coefficient of } \widehat{C}_t\text{)}, = (\alpha_{1V} + \alpha_{1M} + \alpha_{1G}) - (2\alpha_{2V}(1-\mu) - 2\alpha_{2G}\mu)\widehat{T}_{OGV,t} \quad \text{(B.18)}$$

$$\beta_{2C} \text{ (coefficient of } \widehat{C}_t^2\text{)} = -\frac{1}{2}(1-\sigma) + (\alpha_{2V} + \alpha_{2M} + \alpha_{2G}) \quad \text{(B.19)}$$

$$\begin{aligned}\beta_{1TAM} \text{ (coefficient of } \widehat{T}_{AM,t}\text{)} &= (\alpha_{1M}\delta - \alpha_{1V}(1-\delta) - \alpha_{1G}(1-\delta)) \\ &- (2\alpha_{2M}\delta - 2\alpha_{2V}(1-\delta) - 2\alpha_{2G}(1-\delta))\left(\widehat{Y}_{V,t} - (1-\mu)\widehat{T}_{OGV,t}\right) \\ &- (2\alpha_{2G}(1-\delta)\mu - 2\alpha_{2V}(1-\delta)(1-\mu))\widehat{T}_{OGV,t}\end{aligned} \quad \text{(B.20)}$$

$$\begin{aligned}\beta_{2TAM} \text{ (coefficient of } \widehat{T}_{AM,t}^2\text{)} &= \left(\alpha_{2M}\delta^2 + \alpha_{2V}(1-\delta)^2 + \alpha_{2G}(1-\delta)^2\right) \\ &+ (1-\delta)(2\alpha_{2M}\delta - 2\alpha_{2V}(1-\delta) - 2\alpha_{2G}(1-\delta))\end{aligned} \quad \text{(B.21)}$$

$$\beta_{1TOG} \text{ (coefficient of } \widehat{T}_{OG,t}\text{)} = \alpha_{1V}(1-\mu) - \alpha_{1G}\mu \quad \text{(B.22)}$$

$$\beta_{2TOG} \text{ (coefficient of } \widehat{T}_{OG,t}^2\text{)} = \alpha_{2V}(1-\mu)^2 + \alpha_{2G}\mu^2 \quad \text{(B.23)}$$

$$\begin{aligned}w_t \approx & -\frac{U_C\, C}{2}\left[(1-\delta)\left(\theta^{-1}+\psi\right)\theta^2 Var\left\{\widehat{P}_{M,t}(i)\right\} - 2\beta_{1C}\widehat{C}_t\right. \\ & \left. -2\beta_{ITAM}\widehat{T}_{AM,t} - 2\beta_{2TOGV}\widehat{T}_{OGV,t} + 2\beta_{2C}\widehat{C}_t^2 + 2\beta_{2TAM}\widehat{T}_{AM,t}^2 + 2\beta_{2TOGV}\widehat{T}_{OGV,t}^2\right] \\ & + \|O\|^3 + t.i.p.\end{aligned}$$

$$\begin{aligned}w_t \approx & -\frac{U_C\, C}{2}\left[(1-\delta)\left(\theta^{-1}+\psi\right)\theta^2 Var\left\{\widehat{P}_{M,t}(i)\right\} + 2\beta_{2C}\left(\widehat{C}_t^2 - \frac{\beta_{1C}}{\beta_{2C}}\widehat{C}_t\right) + \right. \\ & \left. +2\beta_{2TAM}\left(\widehat{T}_{AM,t}^2 - \frac{\beta_{ITAM}}{\beta_{2TAM}}\widehat{T}_{AM,t}\right) + 2\beta_{2TOGV}\left(\widehat{T}_{OGV,t}^2 - \frac{\beta_{TOGV}}{\beta_{2TOGV}}\widehat{T}_{OGV,t}\right)\right] \\ & + \|O\|^3 + t.i.p.\end{aligned}$$

Note here β_{1C}, β_{1TAM}, β_{1TOGV} are functions of shocks and β_{2C}, β_{2TAM}, β_{2TOGV} are constants.

$$\begin{aligned} w_t \approx & -\frac{U_C\ C}{2}\left[(1-\delta)\left(\theta^{-1}+\psi\right)\theta^2 Var\left\{\widehat{P}_{M,t}(i)\right\}+2\beta_{2C}\left(\widehat{C}_t-\widehat{C}_t^*\right)^2+\right. \\ & \left.+2\beta_{2TAM}\left(\widehat{T}_{AM,t}-\widehat{T}_{AM,t}^*\right)^2+2\beta_{2TOGV}\left(\widehat{T}_{OGV,t}-\widehat{T}_{OGV,t}^*\right)^2\right] \\ & +\|O\|^3+t.i.p. \end{aligned}$$

where $\frac{\beta_{1C}}{2\beta_{2C}}=\widehat{C}_t^*$, $\frac{\beta_{ITAM}}{2\beta_{2TAM}}=\widehat{T}_{AMt}^*$, $\frac{\beta_{TOGV}}{2\beta_{2TOGV}}=\widehat{T}_{OGV,t}^*$. The welfare function reduces to,

$$\begin{aligned} w_t \approx & -\frac{U_C\ C}{2}\left[(1-\delta)\left(\theta^{-1}+\psi\right)\theta^2 Var\left\{\widehat{P}_{M,t}(i)\right\}+2\beta_{2C}\left(\widetilde{C}_t^*\right)^2+\right. \\ & \left.+2\beta_{2TAM}\left(\widetilde{T}_{AM,t}^*\right)^2+2\beta_{2TOGV}\left(\widetilde{T}_{OGV,t}^*\right)^2\right]+\|O\|^3+t.i.p. \end{aligned}$$

where $\widehat{C}_t-\widehat{C}_t^*=\widetilde{C}_t^*$, $\widehat{T}_{AM,t}-\widehat{T}_{AM,t}^*=\widetilde{T}_{AM,t}^*$. Since $\widehat{T}_{OGV,t}=\widehat{T}_{OGV,t}^n$, and $\widehat{T}_{OGV,t}^n$ & $\widehat{T}_{OGV,t}^*$ are functions of shocks, it is t.i.p. The lifetime welfare function is given by,

$$\begin{aligned} E_0\sum_{t=0}^{\infty}\beta^t\left(\frac{w_t}{U_C\ C}\right) \approx & -\frac{1}{2}E_0\sum_{t=0}^{\infty}\beta^t\left[(1-\delta)\left(\theta^{-1}+\psi\right)\theta^2 Var\left\{\widehat{P}_{M,t}(i)\right\}+2\beta_{2C}\left(\widetilde{C}_t^*\right)^2+\right. \\ & \left.+2\beta_{2TAM}\left(\widetilde{T}_{AM,t}^*\right)^2\right]+\|O\|^3+t.i.p. \end{aligned}$$

Using the following result from Woodford (2003),[1]

$$E_0\sum_{t=0}^{\infty}\beta^t Var\left\{\widehat{P}_{M,t}(i)\right\}=\frac{\alpha_M}{(1-\beta\alpha_M)(1-\alpha_M)}E_0\sum_{t=0}^{\infty}\beta^t\pi_{M,t}^2$$

$$\begin{aligned} E_0\sum_{t=0}^{\infty}\beta^t\left(\frac{w_t}{U_C\ C}\right) \approx & -\frac{1}{2}E_0\sum_{t=0}^{\infty}\beta^t\left[\lambda_{\pi M}\left(\pi_{M,t}\right)^2+\lambda_{\widetilde{C}}\left(\widetilde{C}_t^*\right)^2+\right. \\ & \left.+\lambda_{\widetilde{TAM}}\left(\widetilde{T}_{AM,t}^*\right)^2\right]+\|O\|^3+t.i.p. \end{aligned}$$

[1]Refer to Chapter 6 of the book.

where $\lambda_{\pi M} = \frac{\alpha_M(1-\delta)\left(\theta^{-1}+\psi\right)\theta^2}{(1-\beta\alpha_M)(1-\alpha_M)}$, $\lambda_{\widetilde{C}} = 2\beta_{2C}$ and $\lambda_{\widetilde{TAM}} = 2\beta_{2TAM}$. This implies,

$$
\begin{aligned}
E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{w_t}{U_C\ C} \right) \;\; \approx \;\; & -\frac{1}{2}\lambda_{\pi M} E_0 \sum_{t=0}^{\infty} \beta^t \left[\pi_{M,t}^2 + \frac{\lambda_{\widetilde{C}}}{\lambda_{\pi M}} \left(\widetilde{C}_t^* \right)^2 + \right. \\
& \left. + \frac{\lambda_{\widetilde{TAM}}}{\lambda_{\pi M}} \left(\widetilde{T}_{AM,t}^* \right)^2 \right] + \|O\|^3 + t.i.p.
\end{aligned}
$$

B.2 Welfare losses in the absence of procurement

From Chapter 2, composite parameters γ, Θ_1 and Θ_2 are defined as,

$$\gamma = \frac{(\theta-1)(1-c_p)-c_p}{(\theta-1)(1-c_p)};\ \Phi = \frac{c_p}{(\theta-1)(1-c_p)-c_p} \tag{B.24}$$

$$\Theta_1 = \frac{\left(1-c_p s_g \gamma^{[\delta(1-\mu)-1]}\right)\gamma^{-\delta(1-\mu)}}{\gamma^{-\delta(1-\mu)}\left[1+(1-\mu)(\gamma-1)\delta\right]\left(1-c_p s_g \gamma^{[\delta(1-\mu)-1]}\right)+c_p s_g} \tag{B.25}$$

$$\Theta_2 = \frac{c_p s_g}{\gamma^{-\delta(1-\mu)}\left[1+(1-\mu)(\gamma-1)\delta\right]\left(1-c_p s_g \gamma^{[\delta(1-\mu)-1]}\right)+c_p s_g}. \tag{B.26}$$

$$\lambda_c = \gamma^{\delta(1-\mu)-1} c_p s_g \tag{B.27}$$

When $c_p = 0$, $\gamma = 1$, $\Phi = 0$, $\Theta_1 = 1$ $\Theta_2 = 0, \lambda_c = 0$. Substituting these values in the flexible price equilibrium equations (2.56) , (2.52) (2.53)and (2.58) from Chapter 2, we get

$$
\begin{aligned}
\widehat{C}_t^n &= \frac{(\psi+1)}{(\psi+\sigma)}\widehat{A}_t \\
\widehat{T}_{OGV,t}^n &= \widehat{A}_{V,t} - \widehat{A}_{G,t} \\
\widehat{T}_{AM,t}^n &= \widehat{A}_{M,t} - (1-\mu)\,\widehat{A}_{G,t} - \mu\widehat{A}_{V,t} \\
\widehat{Y}_t^n &= \widehat{C}_t^n
\end{aligned}
$$

where, $\widehat{A}_t = (1-\mu)\,\delta\widehat{A}_{G,t} + \mu\delta\widehat{A}_{V,t} + (1-\delta)\,\widehat{A}_{M,t}$. The efficient equilibrium levels for consumption, terms of trade, and output is given by the following:

$$
\begin{aligned}
\widehat{C}_t^* &= \frac{\beta_{1C}}{2\beta_{2C}};\ \widehat{T}_{AM,t}^* = \frac{\beta_{ITAM}}{2\beta_{2TAM}};\ \widehat{T}_{OGV,t}^* = \frac{\beta_{1TOGV}}{2\beta_{2TOGV}} \\
\widehat{Y}_t^* &= (1-\lambda_c)\,\widehat{C}_t^* + \lambda_c[\widehat{Y}_{PG,t} + \mu\widehat{T}_{OGV,t}^* + (1-\delta)\widehat{T}_{AM,t}^*]
\end{aligned}
$$

When $c_p = 0$, α_{1G} and α_{2G}, defined above in equation $(B.15)$ and $(B.16)$ would reduce to the following,

$$
\alpha_{2G} = (1-\mu)\,\delta\left(\frac{1+\psi}{2}\right);\ \alpha_{1G} = (1-\mu)\,\delta\psi g_{OG,t}
$$

Similarly, substituting values of $\alpha_{1G}, \alpha_{1V}, \alpha_{1M}, \alpha_{2G}, \alpha_{2V}, \alpha_{2M}$ in equation $(B.18)-(B.23)$, we get

$$
\begin{aligned}
\beta_{1C} &= \mu\delta\psi g_{V,t} + (1-\delta)\,\psi g_{M,t} + (1-\mu)\,\delta\psi g_{OG,t} \\
\beta_{1TAM} &= (1-\delta)\,\delta\psi\,(g_{M,t} - \mu g_{V,t} - (1-\mu)\,g_{OG,t}) \\
\beta_{2C} &= \left(\frac{\psi+\sigma}{2}\right);\ \beta_{2TAM} = (1-\delta)\left(\frac{\psi+1}{2}\right)\delta \\
\beta_{1TOG} &= \mu\delta\psi\,(1-\mu)\,[g_{V,t} - g_{OG,t}] \\
\beta_{2TOG} &= \mu\delta\left(\frac{\psi+1}{2}\right)(1-\mu)
\end{aligned}
$$

$$
\begin{aligned}
\widehat{C}_t^* &= \frac{\mu\delta\psi g_{V,t} + (1-\delta)\,\psi g_{M,t} + (1-\mu)\,\delta\psi g_{OG,t}}{\psi+\sigma} \\
&= \frac{\mu\delta\,(1+\psi)\,\widehat{A}_{V,t} + (1-\delta)\,(1+\psi)\,\widehat{A}_{M,t} + (1-\mu)\,\delta\,(1+\psi)\,\widehat{A}_{G,t}}{\psi+\sigma} \\
&= \frac{(1+\psi)}{(\psi+\sigma)}\widehat{A}_t = \widehat{C}_t^n
\end{aligned}
$$

$$\begin{aligned}\widehat{T}^{*}_{AM,t} &= \frac{(1+\psi)\,\widehat{A}_{M,t}-\mu\,(1+\psi)\,\widehat{A}_{V,t}-(1-\mu)\,(1+\psi)\,\widehat{A}_{G,t}}{(\psi+1)} \\ &= \widehat{A}_{M,t}-\mu\widehat{A}_{V,t}-(1-\mu)\,\widehat{A}_{G,t}=\widehat{T}^{n}_{AM,t}\end{aligned}$$

$$\widehat{T}^{*}_{OGV,t} = \frac{\left[(1+\psi)\,\widehat{A}_{V,t}-(1+\psi)\,\widehat{A}_{G,t}\right]}{(\psi+1)} = \widehat{A}_{V,t}-\widehat{A}_{G,t}=\widehat{T}^{n}_{OGV,t}$$

$$\widehat{Y}^{*}_{t} = \widehat{C}^{*}_{t}=\widehat{C}^{n}_{t}=\widehat{Y}^{n}_{t}$$

where, $\widehat{A}_t=\mu\delta\widehat{A}_{V,t}+(1-\delta)\,\widehat{A}_{M,t}+(1-\mu)\,\delta\widehat{A}_{G,t}$.

The lifetime welfare function thus becomes,

$$\begin{aligned}W_t &= E_0\sum_{t=0}^{\infty}\beta^t\left(\frac{w_t}{U_C\ C}\right)\approx-\frac{1}{2}E_0\sum_{t=0}^{\infty}\beta^t\left[\lambda_{\pi M}\,(\pi_{M,t})^2+(\sigma+\psi)\left(\widetilde{Y}_t\right)^2\right. \\ &\left.+(\psi+1)\,(1-\delta)\,\delta\left(\widetilde{T}_{AM,t}\right)^2\right]+\|O\|^3+t.i.p.\end{aligned}$$

where, $\widetilde{Y}_t$ and $\widetilde{T}_{AM,t}$ are gaps from the flexible price equilibrium.

B.3 Derivation of the aggregate goods market condition, NKPC & DIS

We need to rewrite the manufacturing sector NKPC, the aggregate goods market condition and the DIS in terms of gaps from the efficient levels (instead of natural levels).

The aggregate goods market clearing condition is given by,

$$\widetilde{Y}_t=(1-\lambda_c)\widetilde{C}_t+\lambda_c(1-\delta)\widetilde{T}_{AM,t}.$$

Adding and subtracting the efficient levels, we get

$$\left(\widehat{Y}_t - \widehat{Y}_t^n\right) \pm \widehat{Y}_t^* = (1-\lambda_c)\left(\widehat{C}_t - \widehat{C}_t^n\right) \pm (1-\lambda_c)\widehat{C}_t^*$$

$$+\lambda_c(1-\delta)\left(\widehat{T}_{AM,t} - \widehat{T}_{AM,t}^n\right) \pm \lambda_c(1-\delta)\widehat{T}_{AM,t}^*.$$

$$\widetilde{C}_t^* = \frac{1}{(1-\lambda_c)}\widetilde{Y}_t^* - \frac{\lambda_c(1-\delta)}{(1-\lambda_c)}\widetilde{T}_{AM,t}^* - \left(\widehat{C}_t^* - \widehat{C}_t^n\right)$$

$$-\frac{\lambda_c(1-\delta)}{(1-\lambda_c)}\left(\widehat{T}_{AM,t}^* - \widehat{T}_{AM,t}^n\right) + \frac{1}{(1-\lambda_c)}\left(\widehat{Y}_t^* - \widehat{Y}_t^n\right)$$

$$= \frac{1}{(1-\lambda_c)}\widetilde{Y}_t^* - \frac{\lambda_c(1-\delta)}{(1-\lambda_c)}\widetilde{T}_{AM,t}^* + z_{1,t}^*$$

$$\text{where } z_{1,t}^* = \frac{1}{(1-\lambda_c)}\left(\widehat{Y}_t^* - \widehat{Y}_t^n\right) - \left(\widehat{C}_t^* - \widehat{C}_t^n\right) - \frac{\lambda_c(1-\delta)}{(1-\lambda_c)}\left(\widehat{T}_{AM,t}^* - \widehat{T}_{AM,t}^n\right).$$

The manufacturing sector NKPC is,

$$\pi_{M,t} = \beta E_t\left\{\pi_{M,t+1}\right\} + \lambda_M\left(\sigma + \psi\Theta_1\right)\widetilde{C}_t + \lambda_M\delta\widetilde{T}_{AM,t}$$

Adding and subtracting relevant the welfare relevant levels, we get

$$\pi_{M,t} = \beta E_t\left\{\pi_{M,t+1}\right\} + \lambda_M\left(\sigma + \psi\Theta_1\right)\left(\widehat{C}_t - \widehat{C}_t^n\right) \pm \lambda_M\left(\sigma + \psi\Theta_1\right)\widehat{C}_t^* + \lambda_M\delta\left(\widehat{T}_{AM,t} - \widehat{T}_{AM,t}^n\right) \pm \lambda_M\delta\widehat{T}_{AM,t}^*$$

$$\pi_{M,t} = \beta E_t\left\{\pi_{M,t+1}\right\} + \lambda_M\left(\sigma + \psi\Theta_1\right)\widetilde{C}_t^* + \lambda_M\delta\widetilde{T}_{AM,t}^* + z_{2,t}^*$$

$$\text{where } z_{2,t}^* = \lambda_M\left(\sigma + \psi\Theta_1\right)\left(\widehat{C}_t^* - \widehat{C}_t^n\right) + \lambda_M\delta\left(\widehat{T}_{AM,t}^* - \widehat{T}_{AM,t}^n\right).$$

The DIS equation is:

$$\widetilde{Y}_t = E_t\{\widetilde{Y}_{t+1}\} - \frac{(1-\lambda_c)}{\sigma}\left[\widehat{R}_t - E_t\left\{\pi_{t+1}\right\} - \widehat{r}_t^n\right] - \lambda_c\left(1-\delta\right)E_t\left\{\Delta\widetilde{T}_{AM,t+1}\right\}$$

Adding and subtracting the efficient levels, we get

$$\begin{aligned}\left(\widehat{Y}_t - \widehat{Y}_t^n\right) \pm \widehat{Y}_t^* &= E_t\left\{\widehat{Y}_{t+1} - \widehat{Y}_{t+1}^n\right\} \pm E_t\left\{\widehat{Y}_{t+1}^*\right\} - \frac{(1-\lambda_c)}{\sigma}\left[\widehat{R}_t - E_t\left\{\pi_{t+1}\right\} - \widehat{r}_t^n\right] \\ &\quad -\lambda_c\left(1-\delta\right)E_t\left\{\Delta\widehat{T}_{AM,t+1} - \Delta\widehat{T}_{AM,t+1}^n\right\} \mp \lambda_c\left(1-\delta\right)E_t\left\{\Delta\widehat{T}_{AM,t+1}^*\right\}\end{aligned}$$

Re-arranging and substituting $\pi_{t+1} = \pi_{M,t+1} + \delta\Delta\widehat{T}_{AM,t+1}$ (as $P_t = P_{A,t}^{\delta}P_{M,t}^{1-\delta}$),

$$\begin{aligned}\widetilde{Y}_t^* &= E_t\left\{\widetilde{Y}_{t+1}^*\right\} - \frac{(1-\lambda_c)}{\sigma}\left[\widehat{R}_t - E_t\left\{\pi_{M,t+1}\right\} - \widehat{r}_t^*\right] + \\ &\quad \left(\frac{(1-\lambda_c)\delta}{\sigma} - \lambda_c\left(1-\delta\right)\right)E_t\left\{\Delta\widetilde{T}_{AM,t+1}^*\right\} \\ \text{where } \widehat{r}_t^* &= \widehat{r}_t^n + E_t\left\{\delta\Delta\widehat{T}_{AM,t+1}^*\right\} - \frac{\lambda_c\sigma\left(1-\delta\right)}{(1-\lambda_c)}E_t\left\{\Delta\widehat{T}_{AM,t+1}^* - \Delta\widehat{T}_{AM,t+1}^n\right\} \\ &\quad -\frac{\sigma}{(1-\lambda_c)}\left(\widehat{Y}_t^* - \widehat{Y}_t^n\right) + \frac{\sigma}{(1-\lambda_c)}E_t\left\{\widehat{Y}_{t+1}^* - \widehat{Y}_{t+1}^n\right\}\end{aligned}$$

B.4 Optimal monetary policy under discretion

We need to minimize the welfare loss function subject to the aggregate NKPC. The Lagrangian is given by,

$$\begin{aligned}L_t &= \min\frac{1}{2}\left[\pi_{M,t}^2 + \frac{\lambda_{\widetilde{C}}}{\lambda_{\pi M}}\left(\widetilde{C}_t^*\right)^2 + \frac{\lambda_{\widetilde{TAM}}}{\lambda_{\pi M}}\left(\widetilde{T}_{AM,t}^*\right)^2\right] \\ &\quad -\phi_1\left[\pi_{M,t} - \lambda_M\left(\sigma + \psi\Theta_1\right)\widetilde{C}_t^* - \lambda_M\delta\widetilde{T}_{AM,t}^* - z_{2,t}^*\right]\end{aligned}$$

The first order conditions are:

$$\begin{aligned}
\frac{\partial L_t}{\partial \pi_{M,t}} &= \pi_{M,t} - \phi_1 = 0 \\
\frac{\partial L_t}{\partial \widetilde{C}_t^*} &= \frac{\lambda_{\widetilde{C}}}{\lambda_{\pi M}}\left(\widetilde{C}_t^*\right) + \phi_1 \lambda_M \left(\sigma + \psi\Theta_1\right) = 0 \\
\frac{\partial L_t}{\partial \widetilde{T}_{AM,t}^*} &= \frac{\lambda_{\widetilde{TAM}}}{\lambda_{\pi M}}\left(\widetilde{T}_{AM,t}^*\right) + \phi_1 \lambda_M \delta = 0
\end{aligned}$$

This implies,

$$\pi_{M,t} = -\frac{\lambda_{\widetilde{TAM}}}{\delta \lambda_M \lambda_{\pi M}} \widetilde{T}_{AM,t}^* \tag{B.28}$$

$$\tag{B.29}$$

$$\widetilde{C}_t^* = -\frac{\lambda_M \left(\sigma + \psi\Theta_1\right) \lambda_{\pi M}}{\lambda_{\widetilde{C}}} \pi_{M,t}$$

We know that,

$$\widetilde{C}_t^* = \frac{1}{(1-\lambda_c)} \widetilde{Y}_t^* - \frac{\lambda_c(1-\delta)}{(1-\lambda_c)} \widetilde{T}_{AM,t}^* + z_{1,t}^*$$

Substituting for $\widetilde{C}_t^*$ in the first order condition, we get

$$\widetilde{Y}_t^* = -\left[\frac{\lambda_M \left(\sigma + \psi\Theta_1\right)(1-\lambda_c)\lambda_{\pi M}}{\lambda_{\widetilde{C}}} + \frac{\lambda_c(1-\delta)\delta\lambda_M\lambda_{\pi M}}{\lambda_{\widetilde{TAM}}}\right] \pi_{M,t} - (1-\lambda_c) z_{1,t}^* \tag{B.30}$$

Let $\left[\frac{\lambda_M(\sigma+\psi\Theta_1)\lambda_{\pi M}}{\lambda_{\widetilde{C}}} + \frac{\lambda_c(1-\delta)\delta\lambda_M\lambda_{\pi M}}{(1-\lambda_c)\lambda_{\widetilde{TAM}}}\right] = X_1$, such that

$$\pi_{M,t} = -\frac{1}{X_1(1-\lambda_c)} \widetilde{Y}_t^* - \frac{1}{X_1} z_{1,t}^*$$

Since $\pi_t = \pi_{M,t} + \delta \Delta \widehat{T}_{AM,t}$,

$$\pi_{M,t} = \pi_t - \delta \Delta \widetilde{T}_{AM,t}^* - z_{3,t}^*$$

where, $z^*_{3,t} = \Delta\widehat{T}^*_{AM,t}$. Substituting $\widetilde{T}^*_{AM,t}$ from the FOC into the above equation, we get

$$\begin{aligned} \pi_{M,t} &= \pi_t + \frac{\delta^2\lambda_M\lambda_{\pi M}}{\lambda_{\widetilde{TAM}}}\Delta\pi_{M,t} - z^*_{3,t} \\ \pi_t &= -\left(1-\frac{\delta^2\lambda_M\lambda_{\pi M}}{\lambda_{\widetilde{TAM}}}\right)\left[\frac{1}{X_1(1-\lambda_c)}\widetilde{Y}^*_t + \frac{1}{X_1}z^*_{1,t}\right] - \frac{\delta^2\lambda_M\lambda_{\pi M}}{\lambda_{\widetilde{TAM}}}\pi_{M,t-1} + z^*_{3,t} \end{aligned} \tag{B.31}$$

Let $\left(1-\frac{\delta^2\lambda_M\lambda_{\pi M}}{\lambda_{\widetilde{TAM}}}\right) = X_2$

$$\pi_t = -\frac{X_2}{X_1(1-\lambda_c)}\widetilde{Y}^*_t - \frac{X_2}{X_2X_1}z^*_{1,t} + z^*_{3,t} - \frac{\delta^2\lambda_M\lambda_{\pi M}}{\lambda_{\widetilde{TAM}}}\pi_{M,t-1}$$

To get the optimal value of manufacturing sector inflation, $\pi_{M,t}$, the consumption gap, $\widetilde{C}^*_t$, the output gap, $\widetilde{Y}^*_t$, the terms of trade gap, $\widetilde{T}^*_{AM,t}$ and aggregate inflation, π_t, we first substitute the value of $\widetilde{C}^*_t$ and $\widetilde{T}^*_{AM,t}$ from equation $(B.28)$ and $(B.29)$ into the NKPC. We get

$$X_3\pi_{M,t} = \beta E_t\left\{\pi_{M,t+1}\right\} + z^*_{2,t}$$

where $X_3 = \left[1+\lambda_M\left(\sigma+\psi\Theta_1\right)\frac{\lambda_M(\sigma+\psi\Theta_1)\lambda_{\pi M}}{\lambda_{\widetilde{C}}} + \frac{\delta^2\lambda_M^2\lambda_{\pi M}}{\lambda_{\widetilde{TAM}}}\right]$. Thus the optimal level $\pi^*_{M,t}$ is

$$\pi_{M,t} = \frac{1}{X_3}\sum_{j=0}^{\infty}\left(\frac{\beta}{X_3}\right)^j z^*_{2,t+j}$$

Substituting this in the first two FOC's, we get the optimal value of $\widetilde{T}^*_{AM,t}$ and $\widetilde{C}^*_t$ as,

$$\begin{aligned} \widetilde{T}^*_{AM,t} &= -\frac{\lambda_{\pi M}\lambda_M\delta}{\lambda_{\widetilde{TAM}}}\frac{1}{X_3}\sum_{j=0}^{\infty}\left(\frac{\beta}{X_3}\right)^j z^*_{2,t+j} \\ \widetilde{C}^*_t &= -\frac{\lambda_M\left(\sigma+\psi\Theta_1\right)\lambda_{\pi M}}{\lambda_{\widetilde{C}}}\frac{1}{X_3}\sum_{j=0}^{\infty}\left(\frac{\beta}{X_3}\right)^j z^*_{2,t+j} \end{aligned}$$

Substituting this into equation $(B.30)$, we get the following optimal value for $\widetilde{Y}_t^*$,

$$\widetilde{Y}_t^* = -(1-\lambda_c)\left[\frac{X_1}{X_3}\sum_{j=0}^{\infty}\left(\frac{\beta}{X_3}\right)^j z_{2,t+j}^* + z_{1,t}^*\right]$$

Substituting this value in equation $(B.31)$, we get the optimal value of aggregate inflation, π_t, as

$$\pi_t = \frac{X_2}{X_1}\left[\frac{X_1}{X_3}\sum_{j=0}^{\infty}\left(\frac{\beta}{X_3}\right)^j z_{2,t+j}^* + z_{1,t}^*\right] - \frac{1}{X_1}z_{1,t}^* + z_{3,t}^* - \frac{\delta^2\lambda_M\lambda_{\pi M}}{X_3\lambda_{\widetilde{TAM}}}\left[\sum_{j=0}^{\infty}\left(\frac{\beta}{X_3}\right)^j z_{2,t-1+j}^*\right]$$

To get the optimal instrument rule, $\widehat{R}_t^*$ we substitute the optimal values of $\widetilde{Y}_t^*$, $\widetilde{T}_{AM,t}^*$ and $\pi_{M,t}$ into the DIS equation. We get,

$$\begin{aligned}\widehat{R}_t^* &= \widehat{r}_t^* - \sigma E_t\left\{\Delta z_{1,t+1}^*\right\} + \frac{1}{X_3}\left[E_t\left\{\sum_{j=0}^{\infty}\left(\frac{\beta}{X_3}\right)^j z_{2,t+1+j}^*\right\}\right. \\ &\left. -\left(\sigma X_1 + \frac{\lambda_{\pi M}\lambda_M\delta}{\lambda_{\widetilde{TAM}}}\frac{\sigma}{(1-\lambda_c)}\left(\frac{(1-\lambda_c)\delta}{\sigma} - \lambda_c(1-\delta)\right)\right)E_t\left\{\sum_{j=0}^{\infty}\left(\frac{\beta}{X_3}\right)^j \Delta z_{2,t+1+j}^*\right\}\right]\end{aligned}$$

Let $\left(\sigma X_1 + \frac{\lambda_{\pi M}\lambda_M\delta}{\lambda_{\widetilde{TAM}}}\frac{\sigma}{(1-\lambda_c)}\left(\frac{(1-\lambda_c)\delta}{\sigma} - \lambda_c(1-\delta)\right)\right) = X_4$. This implies,

$$\widehat{R}_t^* = \widehat{r}_t^* + \frac{(1-X_4)}{X_3}E_t\left\{\sum_{j=0}^{\infty}\left(\frac{\beta}{X_3}\right)^j z_{2,t+1+j}^*\right\} + \frac{X_4}{X_3}E_t\left\{\sum_{j=0}^{\infty}\left(\frac{\beta}{X_3}\right)^j \Delta z_{2,t+j}^*\right\} - \sigma E_t\left\{\Delta z_{1,t+1}^*\right\}$$

B.5 Optimal monetary policy under commitment

The Lagrangian is given by:

$$\begin{aligned}L_t &= \min_{\{\pi_{M,t},\,\widetilde{C}_t^*,\,\widetilde{T}_{AM,t}^*,\widetilde{T}_{OGV,t}^*\}} -\frac{1}{2}\lambda_{\pi M}E_0\sum_{t=0}^{\infty}\beta^t\left[\pi_{M,t}^2 + \frac{\lambda_{\widetilde{C}}}{\lambda_{\pi M}}\left(\widetilde{C}_t^*\right)^2 + \frac{\lambda_{\widetilde{TAM}}}{\lambda_{\pi M}}\left(\widetilde{T}_{AM,t}^*\right)^2\right. \\ &\left. -\phi_t\left(\pi_{M,t} - \beta E_t\left\{\pi_{M,t+1}\right\} - \lambda_M(\sigma+\psi\Theta_1)\widetilde{C}_t^* - \lambda_M\delta\widetilde{T}_{AM,t}^* - z_{2,t}^*\right)\right]\end{aligned}$$

The first order conditions are:

$$\frac{\partial L_t}{\partial \pi_{M,t}} = \pi_{M,t} - \phi_t + \phi_{t-1} = 0 \tag{B.32}$$

$$\frac{\partial L_t}{\partial \widetilde{C}_t^*} = \frac{\lambda_{\widetilde{C}}}{\lambda_{\pi M}} \left(\widetilde{C}_t^* \right) + \phi_t \lambda_M \left(\sigma + \psi \Theta_1 \right) = 0 \tag{B.33}$$

$$\frac{\partial L_t}{\partial \widetilde{T}_{AM,t}^*} = \frac{\lambda_{\widetilde{TAM}}}{\lambda_{\pi M}} \left(\widetilde{T}_{AM,t}^* \right) + \phi_t \lambda_M \delta = 0 \tag{B.34}$$

From equations, $(B.33)$ and $(B.34)$,

$$\phi_t = -\frac{\lambda_{\widetilde{C}}}{\lambda_{\pi M} \lambda_M \left(\sigma + \psi \Theta_1 \right)} \widetilde{C}_t^*$$

$$\text{or } \phi_t = -\frac{\lambda_{\widetilde{TAM}}}{\lambda_{\pi M} \lambda_M \delta} \widetilde{T}_{AM,t}^*$$

such that from $(B.32)$ we get

$$\pi_{M,t} + \frac{\lambda_{\widetilde{C}}}{\lambda_{\pi M} \lambda_M \left(\sigma + \psi \Theta_1 \right)} \widetilde{C}_t^* - \frac{\lambda_{\widetilde{C}}}{\lambda_{\pi M} \lambda_M \left(\sigma + \psi \Theta_1 \right)} \widetilde{C}_{t-1}^* = 0$$

$$\pi_{M,t} + \frac{\lambda_{\widetilde{TAM}}}{\lambda_{\pi M} \lambda_M \delta} \widetilde{T}_{AM,t}^* - \frac{\lambda_{\widetilde{TAM}}}{\lambda_{\pi M} \lambda_M \delta} \widetilde{T}_{AM,t-1}^* = 0$$

Re-writing, we get,

$$\widetilde{C}_t^* = \widetilde{C}_{t-1}^* - \frac{\lambda_{\pi M} \lambda_M \left(\sigma + \psi \Theta_1 \right)}{\lambda_{\widetilde{C}}} \pi_{M,t}$$

$$\widetilde{T}_{AM,t}^* = \widetilde{T}_{AM,t-1}^* - \frac{\lambda_{\pi M} \lambda_M \delta}{\lambda_{\widetilde{TAM}}} \pi_{M,t}$$

Using the value of $\widetilde{C}_t^*$ from aggregate output in the above equation, and substituting the following value of ω_1,

$$\left(\lambda_c(1-\delta)\frac{\lambda_{\pi M}\lambda_M\delta}{\lambda_{\widetilde{TAM}}} + \frac{\lambda_{\pi M}\lambda_M(1-\lambda_c)\left(\sigma+\psi\Theta_1\right)}{\lambda_{\widetilde{C}}}\right),$$

we get

$$\widetilde{Y}_t^* = \widetilde{Y}_{t-1}^* - \omega_1\pi_{M,t} - (1-\lambda_c)\left[z_{1,t}^* - z_{1,t-1}^*\right]$$

We now assume that $\phi_{-1} = 0$, such that,

$$\pi_{M,0} = \phi_0$$

which implies,

$$\begin{aligned}
\pi_{M,0} &= -\frac{\lambda_{\widetilde{TAM}}}{\lambda_{\pi M}\lambda_M\delta}\widetilde{T}_{AM,0}^* \\
&= -\frac{\lambda_{\widetilde{C}}}{\lambda_{\pi M}\lambda_M\left(\sigma+\psi\Theta_1\right)}\widetilde{C}_0^* \\
\text{and } \widetilde{Y}_0^* &= -\omega_1\pi_{M,0} - (1-\lambda_c)z_{1,0}^*
\end{aligned}$$

Writing the above equation recursively,

$$\begin{aligned}
\widetilde{Y}_t^* &= -\omega_1\sum_{k=0}^{t}\pi_{M,t-k} - (1-\lambda_c)\left[\sum_{k=0}^{t}z_{1,t-k}^* - \sum_{k=0}^{t-1}z_{1,t-1-k}^*\right] \\
&= -\omega_1\widehat{\widehat{P}}_{M,t} - (1-\lambda_c)z_{1,t}^*
\end{aligned}$$

where $\widehat{\widehat{P}}_{M,t} = \widehat{P}_{M,t} - \widehat{P}_{M,-1}$. Similarly,

$$\begin{aligned}
\widetilde{C}_t^* &= -\omega_2 \left(\widehat{P}_{M,t} - \widehat{P}_{M,-1} \right) = -\omega_2 \widehat{\widehat{P}}_{M,t} \\
\widetilde{T}_{AM,t}^* &= -\omega_3 \left(\widehat{P}_{M,t} - \widehat{P}_{M,-1} \right) = -\omega_3 \widehat{\widehat{P}}_{M,t}
\end{aligned}$$

$$\text{where } \omega_2 = \frac{\lambda_{\pi M} \lambda_M \left(\sigma + \psi \Theta_1 \right)}{\lambda_{\widetilde{C}}}, \; \omega_3 = \frac{\lambda_{\pi M} \lambda_M \delta}{\lambda_{\widetilde{TAM}}}$$

To get the optimal values of variables, we substitute the value of $\widetilde{C}_t^*, \widetilde{T}_{AM,t}^*$ in the NKPC. Re-writing the NKPC,

$$\begin{aligned}
\widehat{P}_{M,t} - \widehat{P}_{M,t-1} &= \beta E_t \left\{ \widehat{P}_{M,t+1} - \widehat{P}_{M,t} \right\} + \lambda_M \left(\sigma + \psi \Theta_1 \right) \widetilde{C}_t^* + \lambda_M \delta \widetilde{T}_{AM,t}^* + z_{2,t}^* \\
\widehat{\widehat{P}}_{M,t} - \widehat{\widehat{P}}_{M,t-1} &= \beta E_t \left\{ \widehat{\widehat{P}}_{M,t+1} - \widehat{\widehat{P}}_{M,t} \right\} + \lambda_M \left(\sigma + \psi \Theta_1 \right) \widetilde{C}_t^* + \lambda_M \delta \widetilde{T}_{AM,t}^* + z_{2,t}^*
\end{aligned}$$

Substituting values from above,

$$\begin{aligned}
\widehat{\widehat{P}}_{M,t} &= \omega_4 \widehat{\widehat{P}}_{M,t-1} + \beta \omega_4 E_t \left\{ \widehat{\widehat{P}}_{M,t+1} \right\} + \omega_4 z_{2,t}^* \\
\text{where, } \omega_4 &= \frac{1}{1 + \beta + \lambda_M \left(\sigma + \psi \Theta_1 \right) \omega_2 + \lambda_M \delta \omega_3}
\end{aligned}$$

Solving this difference equation,

$$\begin{aligned}
\widehat{\widehat{P}}_{M,t} - \omega_4 \widehat{\widehat{P}}_{M,t-1} - \beta \omega_4 E_t \left\{ \widehat{\widehat{P}}_{M,t+1} \right\} &= \omega_4 z_{2,t}^* \\
\widehat{\widehat{P}}_{M,t-1} \left[-\omega_4 + F - \beta \omega_4 F^2 \right] &= \omega_4 z_{2,t}^*
\end{aligned}$$

such that, $F^n X_t = X_{t+n}$. Let $\varkappa_1$ and $\varkappa_2$ be the roots of the quadratic equation,

$$\varkappa_1 = \frac{1 - \sqrt{1 - 4\beta\omega_4^2}}{2\beta\omega_4} \text{ and } \varkappa_2 = \frac{1 + \sqrt{1 - 4\beta\omega_4^2}}{2\beta\omega_4}$$

Assuming, $\varkappa_2 > 1$,[2]

$$\widehat{\widehat{P}}_{M,t} = \varkappa_1 \widehat{\widehat{P}}_{M,t-1} + \frac{1}{\varkappa_2 \beta} \sum_{k=0}^{\infty} \left(\frac{1}{\varkappa_2} \right)^k z^*_{2,t+k}$$

$$\widetilde{Y}^*_t = -\omega_1 \widehat{\widehat{P}}_{M,t} - (1-\lambda_c) z^*_{1,t}$$

$$\widehat{\widehat{P}}_{M,t} = -\frac{1}{\omega_1} \widetilde{Y}^*_t - \frac{(1-\lambda_c)}{\omega_1} z^*_{1,t}$$

Substituting the value in the optimal price path above, we get

$$\widetilde{Y}^*_t = \varkappa_1 \widetilde{Y}^*_{t-1} - (1-\lambda_c) \left[z^*_{1,t} - \varkappa_1 z^*_{1,t-1} \right] - \frac{\omega_1}{\varkappa_2 \beta} \sum_{k=0}^{\infty} \left(\frac{1}{\varkappa_2} \right)^k z^*_{2,t+k}$$

Similarly,

$$\widetilde{T}^*_{AM,t} = \varkappa_1 \widetilde{T}^*_{AM,t-1} - \frac{\omega_3}{\varkappa_2 \beta} \sum_{k=0}^{\infty} \left(\frac{1}{\varkappa_2} \right)^k z^*_{2,t+k}$$

Rewriting DIS equation after substituting value of $\widetilde{Y}^*_t$ and $\widetilde{T}^*_{AM,t}$, we get

$$\widehat{R}^*_t = \widehat{r}^*_t + \omega_5 E_t \left\{ \widehat{\widehat{P}}_{M,t+1} - \widehat{\widehat{P}}_{M,t} \right\} - \frac{\sigma}{(1-\lambda_c)} (1-\lambda_c) E_t \left\{ z^*_{1,t+1} - z^*_{1,t} \right\}$$

$$\text{where, } \omega_5 = \left[1 - \frac{\sigma}{(1-\lambda_c)} \omega_1 - \frac{\sigma}{(1-\lambda_c)} \left(\frac{(1-\lambda_c)\delta}{\sigma} - \lambda_c (1-\delta) \right) \omega_3 \right]$$

$$\therefore \quad \widehat{R}^*_t = \widehat{r}^*_t + \omega_5 E_t \left\{ \widehat{\widehat{P}}_{M,t+1} - \widehat{\widehat{P}}_{M,t} \right\} - \frac{\sigma}{(1-\lambda_c)} (1-\lambda_c) E_t \left\{ z^*_{1,t+1} - z^*_{1,t} \right\}$$

[2] $\varkappa_2 > 1$ and $\varkappa_1 < 1$ has been verified for the calibrated values of parameters of the model.

Re-writing $\widehat{\widehat{P}}_{M,t}$

$$\begin{aligned} \widehat{\widehat{P}}_{M,t} &= \varkappa_1 \widehat{\widehat{P}}_{M,t-1} + \frac{1}{\varkappa_2 \beta} \sum_{k=0}^{\infty} \left(\frac{1}{\varkappa_2} \right)^k z^*_{2,t+k} \\ &= \frac{1}{\varkappa_2 \beta} \sum_{j=0}^{t} \varkappa_1^j \sum_{k=0}^{\infty} \left(\frac{1}{\varkappa_2} \right)^k z^*_{2,t+k-j} \end{aligned}$$

Therefore,

$$\widehat{R}^*_t = \widehat{r}^*_t + \omega_5 \left(\varkappa_1 - 1 \right) \widehat{\widehat{P}}_{M,t} + \frac{\omega_5}{\varkappa_2 \beta} E_t \sum_{k=0}^{\infty} \left(\frac{1}{\varkappa_2} \right)^k z^*_{2,t+1+k} - \frac{\sigma}{(1-\lambda_c)} (1-\lambda_c) E_t \left\{ z^*_{1,t+1} - z^*_{1,t} \right\}$$

Appendix C

Appendix: Chapter 4

C.1 Data Appendix

C.1.1 Data description for empirical evidence

For the VXO series, we use the CBOE S&P 100 Volatility Index's daily series accessed from the Federal Reserve Bank of St. Louis database from 1996 to 2018. The series is available with daily frequency which we convert to quarterly series by taking simple quarterly averages. We create a quarterly panel data for 12 economies from 1996:Q1 to 2018:Q4. We consider six AEs (US, UK, Canada, Japan, Australia and South Korea) and six EMEs (Brazil, Indonesia, India, Mexico, Russia and South Africa).

The primary source for most of the macroeconomic series is the quarterly national accounts data compiled by the Organization for Economic Cooperation and Development (OECD). We consider a seasonally adjusted volume index for the following series: GDP, private consumption, government consumption and private investment (GFCF). The reference year for the all the data series in the dataset is 2010. For India we consider the nominal series data (for GDP, private consumption, government consumption and private investment (GFCF)) at current prices instead of the volume index data because the volume index data for India is available from 2011:Q1. We later adjust the nominal data series with the CPI (consumer price index) for India to get real indices for all the variables mentioned above.

We create trade balance (total exports-total imports) series from the quarterly nominal data series on total imports and total exports. To normalize the trade balance series we take the ratio of the trade balance to GDP. We get monthly series on nominal exchange rates (currency per US dollar) from the OECD. We create quarterly nominal exchange rate series by taking quarterly averages of the monthly series. The relative consumer price indices (in terms of US dollars) data is used to capture the real effective exchange rate. Any increase (decrease) in the index would thus mean currency appreciation (depreciation).

We use short term interest rate (per annum) series to approximate the nominal interest rate series (policy rate). We also consider money supply measures including broad money and narrow money as control variables for local projections. We consider seasonally adjusted narrow and broad money quarterly indices and adjust them with CPI series to get real narrow and broad money series.

We get the country wise quarterly series on net portfolio investment (US dollars) from the International Monetary Fund's International Financial Statistics (IFS). We also consider the net financial account (except exceptional financing) series as a control in local projections. Finally we create a ratio of net portfolio investment to GDP and net financial account to GDP to normalize the series.

We HP filter following series for the analysis: VXO, real GDP, real private consumption, real government consumption, real private investment, trade balance ratio to GDP, net portfolio investment ratio to GDP, net financial account ratio to GDP, real narrow money and real broad money. The non-filtered series used during the analysis are CPI, nominal exchange rates, relative CPI and short term interest rates.

We run panel data local projections on the above described dataset. To get the impulse response on a single variable, with VXO being an impulse variable, we control for all the variables with lag upto 4 periods over a horizon of 6 periods.

C.1.2 Data description for calibration

We estimate the degree of openness parameter, χ, to be 0.6, as the average trade share to GDP of emerging market economies. To get this we use the World Bank's country level trade data for year 2015. We take the average for 13 emerging market economies, namely: Argentina, Brazil, Chile, Colombia, Costa Rica, Hungary, India, Indonesia, Mexico, Poland, Russia, South Africa and Turkey to get average value as 0.6. We get the trade share of each country as a ratio of the total value of trade of a country with the world to the value of country's GDP, for year 2015.

The value of the initial parameter in the asset market condition, κ, is estimated to be 3.8. From the asset market condition, $\kappa = Q_0 \frac{C_0^{-\nu_D}}{\Gamma_{F,0} C_0^{*-\nu_F}}$ is a function of the initial (beginning of the time period) ratio of marginal utility of the domestic country to the foreign country and real exchange rates. We calculate this using the OECD database on annual national accounts. First, using the exchange rate and the consumption series at constant prices of 2015, we get real consumption series in US dollars. We then calculate the average for EMEs and AEs from 2005-2015. We consider 13 EMEs namely: Argentina, Brazil, Chile, Colombia, Costa Rica, Hungary, India, Indonesia, Mexico, Poland, Russia, South Africa, Turkey, and 31 AEs namely: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, UK and the US. We then calculate the marginal utilities ratio using the utility parameter (inverse of IES) as 1.5. [Calculation: $\kappa = (109293.4/266609)^{-1.5} = 3.8$].

C.2 Technical Appendix

C.2.1 Derivation of the demand functions

Demand for a variety i of domestic good by domestic households

$$\max_{C_{D,t}(i)} C_{D,t} = \left[\left(\frac{1}{n}\right)^{\frac{1}{\sigma}} \int_0^n \left(C_{D,t}\left(i\right)\right)^{\frac{\sigma-1}{\sigma}} di\right]^{\frac{\sigma}{\sigma-1}}$$

subject to constraint,

$$\int_0^n P_{D,t}\left(i\right) C_{D,t}\left(i\right) di = Z_{D,t}$$

$$\mathcal{L}_t = \max_{C_{D,t}(i)} \left[\left[\left(\frac{1}{n}\right)^{\frac{1}{\sigma}} \int_0^n \left(C_{D,t}\left(i\right)\right)^{\frac{\sigma-1}{\sigma}} di\right]^{\frac{\sigma}{\sigma-1}} - \lambda_{D,t}\left(\int_0^n P_{D,t}\left(i\right) C_{D,t}\left(i\right) di - Z_t\right)\right]$$

First order condition,

$$\frac{\partial \mathcal{L}}{\partial C_{D,t}\left(i\right)} = \frac{\sigma}{\sigma-1}\left(C_{D,t}\right)^{\frac{1}{\sigma-1}} \left(\frac{1}{n}\right)^{\frac{1}{\sigma}} \left(C_{D,t}\left(i\right)\right)^{\frac{\sigma-1}{\sigma}-1} - \lambda_{D,t} P_{D,t}\left(i\right) = 0$$

For any two variety i_1, i_2, we get,

$$\begin{aligned} \frac{\left(C_{D,t}\left(i_1\right)\right)^{-\frac{1}{\sigma}}}{\left(C_{D,t}\left(i_2\right)\right)^{-\frac{1}{\sigma}}} &= \frac{P_{D,t}\left(i_1\right)}{P_{D,t}\left(i_2\right)} \\ C_{D,t}\left(i_1\right) &= \left(\frac{P_{D,t}\left(i_1\right)}{P_{D,t}\left(i_2\right)}\right)^{-\sigma} C_{D,t}\left(i_2\right) \end{aligned}$$

Substituting the value in $C_{D,t}$,

$$\begin{aligned}
C_{D,t} &= \left[\left(\frac{1}{n}\right)^{\frac{1}{\sigma}}\int_0^n \left(C_{D,t}\left(i_1\right)\right)^{\frac{\sigma-1}{\sigma}} di_1\right]^{\frac{\sigma}{\sigma-1}} \\
&= \left[\left(\frac{1}{n}\right)^{\frac{1}{\sigma}}\int_0^n \left(\left(\frac{P_{D,t}\left(i_1\right)}{P_{D,t}\left(i_2\right)}\right)^{-\sigma} C_{D,t}\left(i_2\right)\right)^{\frac{\sigma-1}{\sigma}} di_1\right]^{\frac{\sigma}{\sigma-1}} \\
&= \left[\left(\frac{1}{n}\right)^{\frac{1}{\sigma}}\int_0^n P_{D,t}\left(i_1\right)^{1-\sigma} di_1\right]^{\frac{\sigma}{\sigma-1}} \frac{C_{D,t}\left(i_2\right)}{\left(P_{D,t}\left(i_2\right)\right)^{-\sigma}}
\end{aligned}$$

let $\left[\left(\frac{1}{n}\right)\int_0^n P_{D,t}\left(i_2\right)^{1-\sigma} di_2\right]^{\frac{1}{1-\sigma}} = P_{D,t}$.

$$C_{D,t} = \left(\frac{1}{n}\right)^{-1}\left(P_{D,t}\right)^{-\sigma}\frac{C_{D,t}\left(i_2\right)}{\left(P_{D,t}\left(i_2\right)\right)^{-\sigma}}$$

Above equation can be re-arranged for a variety i as,

$$C_{D,t}\left(i\right) = \left(\frac{1}{n}\right)\left(\frac{P_{D,t}\left(i\right)}{P_{D,t}}\right)^{-\sigma} C_{D,t}$$

where,

$$P_{D,t} = \left[\left(\frac{1}{n}\right)\int_0^n P_{D,t}\left(i\right)^{1-\sigma} di\right]^{\frac{1}{1-\sigma}}$$

Substituting the value of $C_{D,t}\left(i\right) = \left(\frac{1}{n}\right)\left(\frac{P_{D,t}(i)}{P_{D,t}}\right)^{-\sigma} C_{D,t}$ in the constraint,

$$\begin{aligned}
\int_0^n P_{D,t}\left(i\right)\left(\frac{1}{n}\right)\left(\frac{P_{D,t}\left(i\right)}{P_{D,t}}\right)^{-\sigma} C_{D,t} di &= Z_{D,t} \\
\left(P_{D,t}\right)^{1-\sigma}\left(P_{D,t}\right)^{\sigma} C_{D,t} &= Z_{D,t} \\
P_{D,t}C_{D,t} &= Z_{D,t}
\end{aligned}$$

Similarly it can be shown,

$$C_{F,t}(i) = \left(\frac{1}{1-n}\right)\left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\sigma} C_{F,t} \text{ ; where } P_{F,t} = \left[\left(\frac{1}{1-n}\right)\int_n^1 P_{F,t}(i)^{1-\sigma}\,di\right]^{\frac{1}{1-\sigma}}$$

$$C^*_{D,t}(i) = \left(\frac{1}{n}\right)\left(\frac{P_{D,t}(i)}{P_{D,t}}\right)^{-\sigma} C^*_{D,t}\text{; where } P^*_{D,t} = \left[\left(\frac{1}{n}\right)\int_0^n P^*_{D,t}(i)^{1-\sigma}\,di\right]^{\frac{1}{1-\sigma}}$$

$$C^*_{F,t}(i) = \left(\frac{1}{1-n}\right)\left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\sigma} C^*_{F,t}\text{; where } P^*_{F,t} = \left[\left(\frac{1}{1-n}\right)\int_n^1 P^*_{F,t}(i)^{1-\sigma}\,di\right]^{\frac{1}{1-\sigma}}$$

by maximizing $C_{F,t} = \left[\left(\frac{1}{1-n}\right)^{\frac{1}{\sigma}}\int_n^1 (C_{F,t}(i))^{\frac{\sigma-1}{\sigma}}\,di\right]^{\frac{\sigma}{\sigma-1}}$ subject to $\int_n^1 P_{F,t}(i)\,C_{F,t}(i)\,di = Z_{F,t}$, $C^*_{D,t} = \left[\left(\frac{1}{n}\right)^{\frac{1}{\sigma}}\int_0^n \left(C^*_{D,t}(i)\right)^{\frac{\sigma-1}{\sigma}}\,di\right]^{\frac{\sigma}{\sigma-1}}$ subject to $\int_0^n P^*_{D,t}(i)\,C^*_{D,t}(i)\,di = Z^*_{D,t}$ and $C^*_{F,t} = \left[\left(\frac{1}{1-n}\right)^{\frac{1}{\sigma}}\int_n^1 \left(C^*_{F,t}(i)\right)^{\frac{\sigma-1}{\sigma}}\,di\right]^{\frac{\sigma}{\sigma-1}}$ subject to $\int_n^1 P^*_{F,t}(i)\,C^*_{F,t}(i)\,di = Z^*_{D,t}$, respectively. It can also be shown that expenditure $Z_{F,t} = P_{F,t}C_{F,t}$, $Z^*_{D,t} = P^*_{D,t}C^*_{D,t}$, $Z^*_{F,t} = P^*_{F,t}C^*_{F,t}$.

For the domestic and foreign goods in the total consumption basket

$$\max_{C_{D,t},C_{F,t}} C_t = \left[(\mu_D)^{1/\xi_D}(C_{D,t})^{\frac{\xi_D-1}{\xi_D}} + (1-\mu_D)^{1/\xi_D}(C_{F,t})^{\frac{\xi_D-1}{\xi_D}}\right]^{\frac{\xi_D}{\xi_D-1}}$$

subject to,

$$P_{D,t}C_{D,t} + P_{F,t}C_{F,t} = Z_t$$

$$\mathcal{L}_t = \left[(\mu_D)^{1/\xi_D}(C_{D,t})^{\frac{\xi_D-1}{\xi_D}} + (1-\mu_D)^{1/\xi_D}(C_{F,t})^{\frac{\xi_D-1}{\xi_D}}\right]^{\frac{\xi_D}{\xi_D-1}} - \lambda_{D,t}\left[P_{D,t}C_{D,t} + P_{F,t}C_{F,t} - Z_t\right]$$

The first order conditions are,

$$\frac{\partial\mathcal{L}}{\partial C_{D,t}} = (C_t)^{\frac{1}{\xi_D-1}}(\mu_D)^{1/\xi_D}(C_{D,t})^{\frac{\xi_D-1}{\xi_D}-1} - \lambda_{D,t}P_{D,t} = 0$$

$$\frac{\partial\mathcal{L}}{\partial C_{F,t}} = (C_t)^{\frac{1}{\xi_D-1}}(1-\mu_D)^{1/\xi_D}(C_{F,t})^{\frac{\xi_D-1}{\xi_D}-1} - \lambda_{D,t}P_{F,t} = 0$$

Combining the above two conditions we get,

$$C_{F,t} = \frac{(1-\mu_D)}{\mu_D}\left(\frac{P_{F,t}}{P_{D,t}}\right)^{-\xi_D} C_{D,t}$$

Substituting this value in the consumption bundle, we get

$$\begin{aligned}
C_t &= \left[(\mu_D)^{1/\xi_D}(C_{D,t})^{\frac{\xi_D-1}{\xi_D}} + (1-\mu_D)^{1/\xi_D}\left(\frac{(1-\mu_D)}{\mu_D}\left(\frac{P_{F,t}}{P_{D,t}}\right)^{-\xi_D} C_{D,t}\right)^{\frac{\xi_D-1}{\xi_D}}\right]^{\frac{\xi_D}{\xi_D-1}} \\
&= \left[\frac{(\mu_D)^{\frac{\xi_D-1}{\xi_D}}(\mu_D)^{1/\xi_D}(P_{D,t})^{1-\xi_D} + (1-\mu_D)^{1/\xi_D}(1-\mu_D)^{\frac{\xi_D-1}{\xi_D}}(P_{F,t})^{1-\xi_D}}{(\mu_D)^{\frac{\xi_D-1}{\xi_D}}(P_{D,t})^{1-\xi_D}}\right]^{\frac{\xi_D}{\xi_D-1}} C_{D,t} \\
&= (\mu_D)^{-1}(P_{D,t})^{\xi_D} C_{D,t}\left[\mu_D (P_{D,t})^{1-\xi_D} + (1-\mu_D)(P_{F,t})^{1-\xi_D}\right]^{\frac{\xi_D}{\xi_D-1}}
\end{aligned}$$

Assuming,

$$P_t = \left[\mu_D (P_{D,t})^{1-\xi_D} + (1-\mu_D)(P_{F,t})^{1-\xi_D}\right]^{\frac{1}{1-\xi_D}}$$

$$C_t = (\mu_D)^{-1}(P_{D,t})^{\xi_D} C_{D,t}(P_t)^{-\xi_D}$$

$$\therefore \quad C_{D,t} = \mu_D (T_{D,t})^{-\xi_D} C_t$$

Similarly substituting,

$$C_{D,t} = \frac{\mu_D}{(1-\mu_D)}\left(\frac{P_{D,t}}{P_{F,t}}\right)^{-\xi_D} C_{F,t}$$

in C_t we get,

$$
\begin{aligned}
C_t &= \left[(\mu_D)^{1/\xi_D} \left(\frac{\mu_D}{(1-\mu_D)} \left(\frac{P_{D,t}}{P_{F,t}} \right)^{-\xi_D} C_{F,t} \right)^{\frac{\xi_D - 1}{\xi_D}} + (1-\mu_D)^{1/\xi_D} \left(C_{F,t} \right)^{\frac{\xi_D - 1}{\xi_D}} \right]^{\frac{\xi_D}{\xi_D - 1}} \\
&= (P_t)^{-\xi_D} \frac{C_{F,t} \left(P_{F,t} \right)^{\xi_D}}{(1-\mu_D)}
\end{aligned}
$$

Re-arranging the above equation,

$$
C_{F,t} = (1-\mu_D) \left(\frac{P_{F,t}}{P_t} \right)^{-\xi_D} C_t
$$

$$
C_{F,t} = (1-\mu_D) \left(T_{F,t} \right)^{-\xi_D} C_t
$$

Substituting the demand functions in the constraint,

$$
\begin{aligned}
P_{D,t} \mu_D \left(\frac{P_{D,t}}{P_t} \right)^{-\xi_D} C_t + P_{F,t} (1-\mu_D) \left(\frac{P_{F,t}}{P_t} \right)^{-\xi_D} C_t &= Z_t \\
\left[\frac{\mu_D \left(P_{D,t} \right)^{1-\xi_D} + (1-\mu_D) \left(P_{F,t} \right)^{1-\xi_D}}{(P_t)^{-\xi_D}} \right] C_t &= Z_t \\
P_t C_t &= Z_t
\end{aligned}
$$

Similarly, maximizing the aggregate consumption bundle C_t^* subject to the expenditure on the bundle:

$$
\max_{C_{D,t}^8, C_{F,t}^*} C_t^* = \left[(\mu_F)^{1/\xi_F} \left(C_{D,t}^* \right)^{\frac{\xi_F - 1}{\xi_F}} + (1-\mu_F)^{1/\xi_F} \left(C_{F,t}^* \right)^{\frac{\xi_F - 1}{\xi_F}} \right]^{\frac{\xi_F}{\xi_F - 1}}
$$

subject to,

$$
P_{D,t}^* C_{D,t}^* + P_{F,t}^* C_{F,t}^* = Z_t^*.
$$

We get the following,

$$
\begin{aligned}
C^*_{D,t} &= \mu_F \left(\frac{P^*_{D,t}}{P^*_t}\right)^{-\xi_F} C^*_t \\
&\text{and} \\
C^*_{F,t} &= (1-\mu_F)\left(\frac{P^*_{F,t}}{P^*_t}\right)^{-\xi_F} C^*_t \\
\text{where } P^*_t &= \left[\mu_F \left(P^*_{D,t}\right)^{1-\xi_F} + (1-\mu_F)\left(P^*_{F,t}\right)^{1-\xi_F}\right]^{\frac{1}{1-\xi_F}}
\end{aligned}
$$

It can also be shown that total expenditure $Z^*_t = P^*_t C^*_t$.

C.2.2 Derivation of Euler's equation and labour supply equation

For domestic households,

$$
\max U(C_t, H_{D,t}) = \frac{(C_t)}{1-\nu_D}^{1-\nu_D} - \omega_D \frac{(H_{D,t})}{1+\eta_D}^{1+\eta_D}
$$

subject to the constraint,

$$
W_{D,t}H_{D,t} + profit_{D,t} = P_t C_t - B_{D,t} + E_t\left\{B_{D,t+1}M_{t,t+1}\right\}
$$

Writing the above constraints in real terms implies,

$$
\begin{aligned}
\frac{W_{D,t}H_{D,t} + profit_t}{P_t} &= \frac{P_t C_t}{P_t} - \frac{B_{D,t}}{P_t} + \frac{E_t\left\{B_{D,t+1}M_{t,t+1}\right\}}{P_t} \\
w_{D,t}T_{D,t}H_{D,t} + \ \Omega_{D,t} &= C_t - \frac{B_{D,t}}{P_t} + \frac{E_t\left\{B_{D,t+1}M_{t,t+1}\right\}}{P_t}
\end{aligned}
$$

where $w_{D,t} = \frac{W_{D,t}}{P_{D,t}}$, $T_{D,t} = \frac{P_{D,t}}{P_t}$ and $\Omega_{D,t}$ are real profits.

Maximizing the utility subject to constraint,

$$\mathcal{L}_t = \max_{C_t, H_{D,t}, B_{D,t+1}} \sum_{t=0}^{\infty} \beta^t \left[U(C_t, H_{D,t}) + \lambda_{D,t} \left(w_{D,t} T_{D,t} H_{D,t} + \ \Omega_{D,t} - \right.\right.$$

$$\left.\left. C_t + \frac{B_{D,t}}{P_t} - \frac{E_t \{B_{D,t+1} M_{t,t+1}\}}{P_t} \right) \right]$$

The first order conditions are as follows,

$$\frac{\partial \mathcal{L}_t}{\partial C_t} = U'_{C_t} - P_t \lambda_{D,t} = 0$$

$$\frac{\partial \mathcal{L}_t}{\partial H_{D,t}} = U'_{H_{D,t}} + \lambda_{D,t} w_{D,t} T_{D,t} = 0$$

$$\frac{\partial \mathcal{L}}{\partial B_{D,t+1}} = -\frac{\lambda_{D,t} E_t \{M_{t,t+1}\}}{P_t} + \beta E_t \left\{ \frac{\lambda_{D,t+1}}{P_{t+1}} \right\} = 0$$

where for the considered utility function, $U'_{C_t} = (C_t)^{-\nu_D}$, $U'_{H_{D,t}} = -\omega_D (H_{D,t})^{\eta_D}$, thus

$$\begin{aligned} \lambda_{D,t} &= (C_t)^{-\nu_D} \\ \lambda_{D,t} &= \frac{\omega_D (H_{D,t})^{\eta_D}}{w_{D,t} T_{D,t}} \\ E_t \{\pi_{t+1} M_{t,t+1}\} &= \beta \frac{E_t \{\lambda_{D,t+1}\}}{\lambda_{D,t}} \\ \text{where } E_t \{M_{t,t+1}\} &= \frac{1}{(1 + R_t)} \end{aligned}$$

Similarly for foreign households,

$$\max U(C_t^*, H_{F,t}) = \frac{\Gamma_{F,t} (C_t^*)^{1-\nu_F}}{1 - \nu_F} - \omega_F \frac{(H_{F,t})^{1+\eta_F}}{1 + \eta_F}$$

subject to the constraint,

$$W_{F,t} H_{F,t} + profit_{F,t} = P_t^* C_t^* - B_{F,t} + B_{F,t+1} E_t \left\{ M_{t,t+1}^* \right\}$$

Writing the above constraints in real terms,

$$\begin{aligned}
\frac{W_{F,t}H_{F,t} + profit_t^*}{P_t^*} &= \frac{P_t^* C_t^*}{P_t^*} - \frac{B_{F,t}}{P_t^*} + \frac{E_t\left\{M_{t,t+1}^* B_{F,t+1}\right\}}{P_t^*} \\
w_{F,t}\frac{T_{F,t}}{Q_t}H_{F,t} + \ \Omega_t^* &= C_t^* - \frac{B_{F,t}}{P_t^*} + \frac{E_t\left\{M_{t,t+1}^* B_{F,t+1}\right\}}{P_t^*}
\end{aligned}$$

where $w_{F,t} = \frac{W_{F,t}}{P_{F,t}^*}$, $T_{F,t} = \frac{P_{F,t}}{P_t}, Q_t = \frac{X_t P_t^*}{P_t}, \pi_t^* = \frac{P_{t+1}^*}{P_t^*}$ and Ω_t^* are real profits.

Maximizing the utility subject to constraint,

$$\mathcal{L}_t = \max_{C_t^*, H_{F,t}, B_{F,t+1}} \sum_{t=0}^{\infty} \beta^t \left[U(C_t^*, H_{F,t}) + \lambda_{F,t}\left(w_{F,t}\frac{T_{F,t}}{Q_t}H_{F,t} + \ \Omega_t^* - C_t^* + \frac{B_{F,t}}{P_t^*} - \frac{E_t\left\{M_{t,t+1}^* B_{F,t+1}\right\}}{P_t^*} \right) \right]$$

The first order conditions are as follows,

$$\frac{\partial \mathcal{L}}{\partial C_t^*} = U'_{C_t^*} - \lambda_{F,t} = 0$$

$$\frac{\partial \mathcal{L}}{\partial H_{F,t}} = U'_{H_{F,t}} + \lambda_{F,t} w_{F,t}\frac{T_{F,t}}{Q_t} = 0$$

$$\frac{\partial \mathcal{L}}{\partial B_{F,t+1}} = -\frac{\lambda_{F,t} E_t\left\{M_{t,t+1}^*\right\}}{P_t^*} + \beta\frac{\lambda_{F,t+1}}{P_{t+1}^*} = 0$$

where for the considered utility function, $U'_{C_t^*} = \Gamma_{F,t}\left(C_t^*\right)^{-\nu_F}, U'_{H_{F,t}} = -\omega_F\left(H_{F,t}\right)^{\eta_F}$

$$\begin{aligned}
\lambda_{F,t} &= \Gamma_{F,t}\left(C_t^*\right)^{-\nu_F} \\
\lambda_{F,t} &= \frac{\omega_F\left(H_{F,t}\right)^{\eta_F} Q_t}{w_{F,t}T_{F,t}} \\
E_t\left\{\pi_{t+1}^* M_{t,t+1}^*\right\} &= \beta\frac{E_t\left\{\lambda_{F,t+1}\right\}}{\lambda_{F,t}} \\
\text{where } E_t\left\{M_{t,t+1}^*\right\} &= \frac{1}{(1+R_t^*)}
\end{aligned}$$

C.2.3 Derivation of price-setting equations

For domestic firms: since the domestic sector is a sticky price sector, $(1-\alpha_D)$ firms which can optimize, maximize the following profit function,

$$\max_{\overline{P}_{D,t}(i)} \sum_{k=0}^{\infty} \alpha_D^k M_{t,t+k} \left(\overline{P}_{D,t}(i) Y_{D,t_{+k}}(i) - MC_{D,t+k} Y_{D,t_{+k}}(i)\right)$$

$$\text{where } Y_{D,t+k}(i) = \left(\frac{\overline{P}_{D,t}(i)}{P_{D,t+k}}\right)^{-\sigma} Y_{D,t+k}$$

$$\begin{aligned}
\frac{\partial \mathcal{L}_t}{\partial \overline{P}_{D,t}(i)} &= \sum_{k=0}^{\infty} \alpha_D^k M_{t,t+k} \left(Y_{D,t+k}(i) + \overline{P}_{D,t}(i) \frac{\partial Y_{D,t+k}(i)}{\partial \overline{P}_{D,t}(i)} - MC_{D,t+k} \frac{\partial Y_{D,t+k}(i)}{\partial \overline{P}_{D,t}(i)}\right) = 0 \\
where \ \frac{\partial Y_{D,t+k}(i)}{\partial \overline{P}_{D,t}(i)} &= -\sigma \left(\frac{\overline{P}_{D,t}(i)}{P_{D,t+k}}\right)^{-\sigma} \frac{1}{\overline{P}_{D,t}(i)} Y_{D,t+k} \\
&= -\sigma \frac{Y_{D,t+k}(i)}{\overline{P}_{D,t}(i)}
\end{aligned}$$

Therefore,

$$\sum_{k=0}^{\infty} \alpha_D^k M_{t,t+k} \left(Y_{D,t+k}(i) + \overline{P}_{D,t}(i) \left(-\sigma \frac{Y_{D,t+k}(i)}{\overline{P}_{D,t}(i)}\right) - MC_{D,t+k} \left(-\sigma \frac{Y_{D,t+k}(i)}{\overline{P}_{D,t}(i)}\right)\right) = 0$$

$$\overline{P}_{D,t}(i) = \frac{\sigma}{\sigma - 1} \frac{\sum_{k=0}^{\infty} \alpha_D^k M_{t,t+k} MC_{D,t+k} Y_{D,t+k}(i)}{\sum_{k=0}^{\infty} \alpha_D^k M_{t,t+k} Y_{D,t+k}(i)}$$

The remaining α_D share of the firms keep their price the same as the aggregate of last year prices, such that the aggregate price in the manufacturing sector is

$$(P_{D,t}(i))^{-\sigma} = \alpha_D (P_{D,t-1}(i))^{-\sigma} + (1-\alpha_D) \left(\overline{P}_{D,t}(i)\right)^{-\sigma}$$

Writing the price equation recursively, note that the stochastic discount factor, $M_{t,t+k}$, is given by

$$M_{t,t+k} = \frac{1}{(1+R_t)}$$

Now from the household's optimization,

$$M_{t,t+k} = \beta^k \frac{\lambda_{D,t+k}}{\lambda_{D,t}} \frac{P_t}{P_{t+k}}$$

$$\begin{aligned}
\overline{P}_{D,t}(i) &= \frac{\sigma}{\sigma-1} \frac{\sum_{k=0}^{\infty} \alpha_D^k M_{t,t+k} \frac{MC_{D,t+k}}{P_{D,t+k}} P_{D,t+k} \left(\frac{\overline{P}_{D,t}(i)}{P_{D,t+k}}\right)^{-\sigma} Y_{D,t+k}}{\sum_{k=0}^{\infty} \alpha_D^k M_{t,t+k} \left(\frac{\overline{P}_{D,t}(i)}{P_{D,t+k}}\right)^{-\sigma} Y_{D,t+k}} \\
&= \frac{\sigma}{\sigma-1} \frac{\sum_{k=0}^{\infty} \alpha_D^k \beta^k \frac{\lambda_{D,t+k}}{\lambda_{D,t}} \frac{P_t}{P_{t+k}} mc_{D,t+k} \left(P_{D,t+k}\right)^{\sigma+1} Y_{D,t+k}}{\sum_{k=0}^{\infty} \alpha_D^k \beta^k \frac{\lambda_{D,t+k}}{\lambda_{D,t}} \frac{P_t}{P_{t+k}} \left(P_{D,t+k}\right)^{\sigma} Y_{D,t+k}} \\
&= \frac{\sigma}{\sigma-1} \frac{\sum_{k=0}^{\infty} \left(\alpha_D \beta\right)^k \lambda_{D,t+k} mc_{D,t+k} T_{D,t+k} \left(P_{D,t+k}\right)^{\sigma} Y_{D,t+k}}{\sum_{k=0}^{\infty} \left(\alpha_D \beta\right)^k \lambda_{D,t+k} T_{D,t+k} \left(P_{D,t+k}\right)^{\sigma-1} Y_{D,t+k}}
\end{aligned}$$

$$\begin{aligned}
\frac{\overline{P}_{D,t}}{P_{D,t-1}} &= \frac{\sigma}{\sigma-1} \frac{\sum_{k=0}^{\infty} \left(\alpha_D \beta\right)^k \lambda_{D,t+k} mc_{D,t+k} T_{D,t+k} \left(\frac{P_{D,t+k}}{P_{D,t-1}}\right)^{\sigma} Y_{D,t+k}}{\sum_{k=0}^{\infty} \left(\alpha_D \beta\right)^k \lambda_{D,t+k} T_{D,t+k} \left(\frac{P_{D,t+k}}{P_{D,t-1}}\right)^{\sigma-1} Y_{D,t+k}} \\
\overline{\pi}_{D,t} &= \frac{\sigma}{\sigma-1} \frac{\sum_{k=0}^{\infty} \left(\alpha_D \beta\right)^k \lambda_{D,t+k} mc_{D,t+k} T_{D,t+k} \left(\pi_{D,t} \times \pi_{D,t+1} \times \pi_{D,t+2} \times .....\pi_{D,t+k}\right)^{\sigma} Y_{D,t+k}}{\sum_{k=0}^{\infty} \left(\alpha_D \beta\right)^k \lambda_{D,t+k} T_{D,t+k} \left(\pi_{D,t} \times \pi_{D,t+1} \times \pi_{D,t+2} \times .....\pi_{D,t+k}\right)^{\sigma-1} Y_{D,t+k}}
\end{aligned}$$

We can write $\pi^*_{D,t}$ in recursive form,

$$\overline{\pi}_{D,t} = \frac{\sigma}{\sigma-1} \pi_{D,t} \frac{X_{D,t}}{Z_{D,t}}$$

where,

$$X_{D,t} = \lambda_{D,t} Y_{D,t} mc_{D,t} T_{D,t} + \alpha_D \beta \left(\pi_{D,t+1}\right)^{\sigma} E_t \left\{X_{D,t+1}\right\}$$

$$Z_{D,t} = \lambda_{D,t} Y_{D,t} T_{D,t+k} + \alpha_D \beta \left(\pi_{D,t+1}\right)^{\sigma-1} E_t \left\{Z_{D,t+1}\right\}$$

Aggregate prices for domestically produced goods is given by,

$$\begin{aligned}
P_{D,t} &= \left[\left(\frac{1}{n}\right) \int_0^n P_{D,t}(i)^{1-\sigma}\, di\right]^{\frac{1}{1-\sigma}} \\
&\quad i \text{ is a variety here.} \\
\left(P_{D,t}\right)^{(1-\sigma)} &= \left(\frac{1}{n}\right)\left[\int_0^{n\alpha_D} P_{D,t-1}(i)^{1-\sigma} di + \int_{n\alpha_D}^{n} \overline{P}_{D,t}(i)^{1-\sigma} di\right] \\
&= \left(\frac{1}{n}\right)\left[n\alpha_D \left(P_{D,t-1}(i)\right)^{1-\sigma} + n\left(1-\alpha_D\right)\left(\overline{P}_{D,t}(i)\right)^{1-\sigma}\right] \\
&\quad \text{dropping } i \text{ due to symmetry,} \\
\left(P_{D,t}\right)^{(1-\sigma)} &= \alpha_D \left(P_{D,t-1}\right)^{1-\sigma} + \left(1-\alpha_D\right)\left(\overline{P}_{D,t}\right)^{1-\sigma}
\end{aligned}$$

$$\therefore \quad P_{D,t} = \left[\alpha_D \left(P_{D,t-1}\right)^{1-\sigma} + \left(1-\alpha_D\right)\left(\overline{P}_{D,t}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$$

Re-writing this in recursive form yields,

$$\frac{P_{D,t}}{P_{D,t-1}} = \left[\alpha_D \left(\frac{P_{D,t-1}}{P_{D,t-1}}\right)^{1-\sigma} + \left(1-\alpha_D\right)\left(\frac{\overline{P}_{D,t}}{P_{D,t-1}}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$$

$$\pi_{D,t} = \left[\alpha_D + \left(1-\alpha_D\right)\left(\overline{\pi}_{D,t}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$$

Similarly for foreign firms, where $(1-\alpha_F)$ firms can optimize, they maximize the following profit function,

$$\max_{\overline{P}_{F,t}(i)} \sum_{k=0}^{\infty} \alpha_F^k M_{t,t+k}^* \left(\overline{P}_{F,t}(i) Y_{F,t_{+k}}(i) - MC_{F,t+k} Y_{F,t_{+k}}(i)\right)$$

$$\text{where } Y_{F,t+k}(i) = \left(\frac{\overline{P}_{F,t}(i)}{P^*_{F,t+k}}\right)^{-\sigma} Y_{F,t+k}$$

To get the price setting equation,

$$\overline{P}_{F,t}(i) = \frac{\sigma}{\sigma-1}\frac{\sum_{k=0}^{\infty}\alpha_F^k M^*_{t,t+k} MC_{F,t+k} Y_{F,t+k}(i)}{\sum_{k=0}^{\infty}\alpha_F^k M^*_{t,t+k} Y_{F,t+k}(i)}$$

which can written recursively as,

$$\overline{\pi}_{F,t} = \frac{\sigma}{\sigma-1}\pi^*_{F,t}\frac{X_{F,t}}{Z_{F,t}}$$

where,

$$\begin{aligned} X_{F,t} &= \lambda_{F,t} Y_{F,t} mc_{F,t}\frac{T_{F,t}}{Q_t} + \alpha_F\beta\left(\pi^*_{F,t+1}\right)^{\sigma} E_t\left\{X_{F,t+1}\right\} \\ Z_{F,t} &= \lambda_{F,t} Y_{F,t}\frac{T_{F,t}}{Q_t} + \alpha_F\beta\left(\pi^*_{F,t+1}\right)^{\sigma-1} E_t\left\{Z_{F,t+1}\right\} \end{aligned}$$

The aggregate foreign producer's price inflation is given by,

$$\pi^*_{F,t} = \left[\alpha_F + (1-\alpha_F)\left(\overline{\pi}_{F,t}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$$

C.2.4 Equilibrium

Aggregate demand functions for the domestic and foreign produce

Total demand for each variety i of the output produced by domestic firms,

$$\begin{aligned} Y_{D,t}(i) &= C_{D,t}(i) = nC_{D,t}(i) + (1-n)\,C^*_{D,t}(i) \\ &= n\left(\frac{1}{n}\right)\left(\frac{P_{D,t}(i)}{P_{D,t}}\right)^{-\sigma} C_{D,t} + (1-n)\left(\frac{1}{n}\right)\left(\frac{P^*_{D,t}(i)}{P^*_{D,t}}\right)^{-\sigma} C^*_{D,t} \end{aligned}$$

Note, $P_{D,t}(i) = X_t P^*_{D,t}(i)$, $P_{D,t} = X_t P^*_{D,t}$, where X_t is the nominal exchange rate. Real exchange rate $Q_t = \frac{X_t P^*_t}{P_t}$, $T_t = \frac{P_{F,t}}{P_{D,t}}$ Thus,

$$
\begin{aligned}
Y_{D,t}(i) &= n\left(\frac{1}{n}\right)\left(\frac{P_{D,t}(i)}{P_{D,t}}\right)^{-\sigma} C_{D,t} + (1-n)\left(\frac{1}{n}\right)\left(\frac{P_{D,t}(i)}{P_{D,t}}\right)^{-\sigma} C^*_{D,t} \\
&= \left(\frac{P_{D,t}(i)}{P_{D,t}}\right)^{-\sigma}\left[C_{D,t} + \left(\frac{1-n}{n}\right) C^*_{D,t}\right] \\
&= \left(\frac{P_{D,t}(i)}{P_{D,t}}\right)^{-\sigma} Y_{D,t}
\end{aligned}
$$

Total demand for agricultural produce, $Y_{D,t} = C_{D,t} + \left(\frac{1-n}{n}\right) C^*_{D,t}$. Aggregate demand, $Y_{D,t}$, can be re-written as,

$$
\begin{aligned}
Y_{D,t} &= C_{D,t} + \left(\frac{1-n}{n}\right) C^*_{D,t} \\
&= \mu_D \left(\frac{P_{D,t}}{P_t}\right)^{-\xi_D} C_t + \left(\frac{1-n}{n}\right)\mu_F\left(\frac{P^*_{D,t}}{P^*_t}\right)^{-\xi_F} C^*_t \\
&= \left(\frac{P_{D,t}}{P_t}\right)^{-\xi_D}\left[\mu_D C_t + \left(\frac{1-n}{n}\right)\mu_F\left(\frac{P^*_{D,t}}{P^*_t}\right)^{-\xi_F}\left(\frac{P_t}{P_{D,t}}\right)^{-\xi_D} C^*_t\right] \\
&= \left(\frac{P_{D,t}}{P_t}\right)^{-\xi_D}\left[\mu_D C_t + \left(\frac{1-n}{n}\right)\mu_F\left(\frac{X_t P_{D,t}}{X_t P_t Q_t}\right)^{-\xi_F}\left(\frac{P_{D,t}}{P_t}\right)^{\xi_D} C^*_t\right] \\
&= \left(\frac{P_{D,t}}{P_t}\right)^{-\xi_D}\left[\mu_D C_t + \left(\frac{1-n}{n}\right)\mu_F Q_t^{\xi_F}\left(\frac{P_{D,t}}{P_t}\right)^{\xi_D-\xi_F} C^*_t\right] \\
&= (T_{D,t})^{-\xi_D}\left[\mu_D C_t + \left(\frac{1-n}{n}\right)\mu_F Q_t^{\xi_F}(T_{D,t})^{\xi_D-\xi_F} C^*_t\right]
\end{aligned}
$$

Similarly, total demand for each variety i of the output produced by foreign firms can be written as,

$$
\begin{aligned}
Y_{F,t}(i) &= C_{F,t}(i) = nC_{F,t}(i) + (1-n)\,C^*_{F,t}(i) \\
&= n\left(\frac{1}{1-n}\right)\left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\sigma} C_{F,t} + \left(\frac{1-n}{1-n}\right)\left(\frac{P^*_{F,t}(i)}{P^*_{F,t}}\right)^{-\sigma} C^*_{F,t} \\
&= \left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\sigma} Y_{F,t}
\end{aligned}
$$

where total demand for agricultural produce, $Y_{F,t} = \frac{n}{(1-n)} C_{F,t} + C^*_{F,t}$. Aggregate demand, $Y_{F,t}$, can be re-written as,

$$
\begin{aligned}
Y_{F,t} &= \frac{n}{(1-n)} C_{F,t} + C^*_{F,t} \\
&= \frac{n}{(1-n)}\,(1-\mu_D)\left(\frac{P_{F,t}}{P_t}\right)^{-\xi_D} C_t + (1-\mu_F)\left(\frac{P^*_{F,t}}{P^*_t}\right)^{-\xi_F} C^*_t \\
&= \frac{n}{(1-n)}\,(1-\mu_D)\left(\frac{P_{F,t}}{P_t}\right)^{-\xi_D} C_t + (1-\mu_F)\left(\frac{X_t P_{F,t}}{X_t Q_t P_t}\right)^{-\xi_F} C^*_t \\
&= \left(\frac{P_{F,t}}{P_t}\right)^{-\xi_D}\left[\frac{n}{(1-n)}\,(1-\mu_D)\,C_t + (1-\mu_F)\,Q_t^{\xi_F}\left(\frac{P_{F,t}}{P_t}\right)^{-\xi_F}\left(\frac{P_{F,t}}{P_t}\right)^{\xi_D} C^*_t\right] \\
&= (T_{F,t})^{-\xi_D}\left[\frac{n}{(1-n)}\,(1-\mu_D)\,C_t + (1-\mu_F)\,Q_t^{\xi_F}\,(T_{F,t})^{\xi_D-\xi_F}\, C^*_t\right]
\end{aligned}
$$

Labour market equilibrium

For the domestic country, aggregate labour supply would equalize aggregate labour demand in equilibrium,

$$
\begin{aligned}
H_{D,t} &= \frac{1}{n}\int_0^n H_{D,t}(i)\,di \\
&= \frac{1}{n}\int_0^n \frac{Y_{D,t}(i)}{A_{D,t}}di \\
&= \frac{Y_{D,t}}{A_{D,t}} Disp_{D,t} \\
\text{where } Disp_{D,t} &= \frac{1}{n}\int_0^n \left(\frac{P_{D,t}(i)}{P_{D,t}}\right)^{-\sigma} di
\end{aligned}
$$

Re-writing $Disp_{D,t}$ in recursive form,

$$
\begin{aligned}
Disp_{D,t} &= \frac{1}{n}\int_0^n \frac{\alpha_D \left(P_{D,t-1}(i)\right)^{-\sigma} + (1-\alpha_D)\left(\overline{P}_{D,t}(i)\right)^{-\sigma}}{\left(P_{D,t}\right)^{-\sigma}} di \\
&= \alpha_D \frac{1}{n}\int_0^n \left(\frac{P_{D,t-1}(i)}{P_{D,t}}\right)^{-\sigma} di + (1-\alpha_D)\frac{1}{n}\int_0^n \left(\frac{\overline{P}_{D,t}(i)}{P_{D,t}}\right)^{-\sigma} di \\
&= \alpha_D \frac{1}{n}\int_0^n \left(\frac{P_{D,t-1}(i)}{P_{D,t}}\frac{P_{D,t-1}}{P_{D,t-1}}\right)^{-\sigma} di + (1-\alpha_D)\left(\frac{\overline{P}_{D,t}}{P_{D,t}}\right)^{-\sigma} \\
&= \alpha_D \left(\frac{P_{D,t-1}}{P_{D,t}}\right)^{-\sigma} Disp_{D,t-1} + (1-\alpha_D)\left(\frac{\overline{P}_{D,t}}{P_{D,t}}\frac{P_{D,t-1}}{P_{D,t-1}}\right)^{-\sigma}
\end{aligned}
$$

$$
\begin{aligned}
Disp_{D,t} &= \alpha_D \left(\pi_{D,t}\right)^{\sigma} Disp_{D,t-1} + (1-\alpha_D)\left(\overline{\pi}_{D,t}\right)^{-\sigma}\left(\pi_{D,t}\right)^{\sigma} \\
&= \left(\pi_{D,t}\right)^{\sigma}\left[\alpha_D Disp_{D,t-1} + (1-\alpha_D)\left(\overline{\pi}_{D,t}\right)^{-\sigma}\right]
\end{aligned}
$$

where $Disp_{D,t-1} = \frac{1}{n}\int_0^n \left(\frac{P_{D,t-1}(i)}{P_{D,t-1}}\right)^{-\sigma} di.$

Similarly, in the foreign country labour supply in equilibrium would be,

$$\begin{aligned} H_{F,t} &= \frac{Y_{F,t}}{A_{F,t}} Disp_{F,t} \\ \text{where } Disp_{F,t} &= \left(\frac{1}{1-n}\right) \int_n^1 \left(\frac{P^*_{F,t}(i)}{P^*_{F,t}}\right)^{-\sigma} di \end{aligned}$$

and $Disp_{F,t}$ can be written recursively as,

$$Disp_{F,t} = \left(\pi^*_{F,t}\right)^{\sigma} \left[\alpha_F Disp_{F,t-1} + (1-\alpha_F)\left(\overline{\pi}_{F,t}\right)^{-\sigma}\right]$$

where $Disp_{F,t-1} = \left(\frac{1}{1-n}\right) \int_n^1 \left(\frac{P^*_{F,t-1}(i)}{P^*_{F,t-1}}\right)^{-\sigma} di.$

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